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Focus on Weighing

Modern Maintenance Methods

page 34

Access Intelligence

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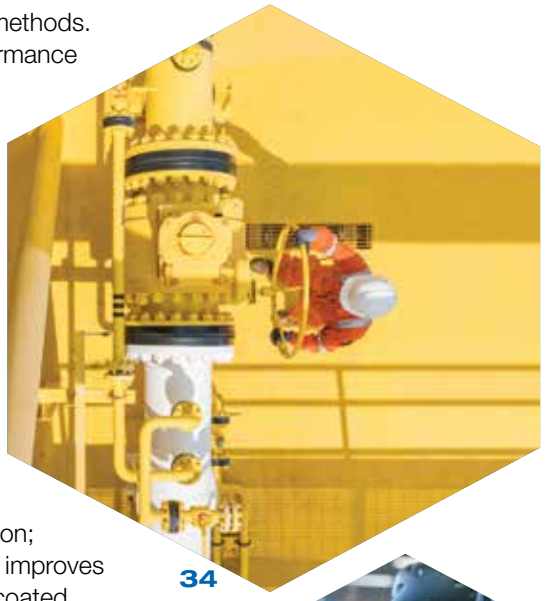
May 2019 Volume 125 | no. 5

Cover Story

34 **Part 1 Maintenance: Pursuing Improvements in Rotating Machinery** The diversity of rotating equipment used in chemical manufacturing creates the need for diverse maintenance methods. Using new technologies can greatly improve the reliability and performance of all types of rotating machines

42 **Part 2 Maintenance Strategies in the Era of IIoT** The shift from reactive to prescriptive maintenance can be greatly aided by advanced digital tools and the implementation of an effective pilot program

48 **Part 3 Modern Instrumentation Simplifies Maintenance** Built-in diagnostics and condition monitoring improve maintenance, process reliability and plant availability



In the News

7 **Chementator**
Impinging jet mixers are applied to bio-crude harvesting from algae; Enzyme engineering enables bio-based hydrogen peroxide production; Protecting oxidation-prone materials by a crust of salt; This process improves blends of starch-based plastic with conventional polyolefins; Nano-coated salts for energy storage; and more

12 **Business News**
Arkema starts up photocure resin expansion in China; Evonik to expand production capacity for transportation polyamides; Ineos to double planned capacity of U.S. Gulf Coast ethylene oxide plant; Eastman acquires Marlotherm business unit from Sasol; and more

14 **Newsfront** **U.S. Refiners Reckon with Uncertain Energy Future** Many indicators point to current success and prosperity for U.S. petroleum refiners, but simultaneously, the industry is facing a future with massive changes in energy and transportation

18 **Newsfront** **Smart Sensors Enable Industry 4.0**
Coupled with advanced analytics and networking capabilities, today's smart sensors help processors optimize the facility

Technical and Practical

30 **Facts at your Fingertips** **Low-Temperature Handling Considerations** This one-page reference provides information on the safety and process challenges associated with very low-temperature fluids

32 **Technology Profile** **Polyethylene Furanoate Production** This column outlines a production process for polyethylene furanoate (PEF), a potential bio-based analog of polyethylene terephthalate

52 **Feature Report** **The Role of Frequency in Radar Level Measurement** No single frequency is suitable for all applications in the CPI. Understanding the principles behind the technology will help in selecting the right device

56

66

24

26

56 **Environmental Manager** **Key Questions to Guide Effective Selection of Personal Protective Equipment**
Armed with a proper understanding of chemical exposure risks and available safety solutions, engineers can be confident in selecting the best personal protective equipment (PPE) to provide reliable barriers to workplace hazards

66 **You and Your Job** **Engineering Internships: A Win for Students and Companies** Insights into the benefits of internships, for both students and the employing companies, are discussed

Equipment and Services

24 **Focus on Weighing**
This load cell is robust and hygienic; New CIP, open-source checkweighing machines; A new compact class for weighing technology; This weight indicator can be hosed down; Two new weight transmitters for automation applications; A checkweigher that also sorts tablets; and more

26 **New Products**
Energy-conservation module improves pneumatic processes; Pump hazardous media at flowrates up to 1,200 m^3/h; This dust collector has two cartidges and higher capacity; A new non-contact radar gage for liquid-level measurement; Hybrid gas analyzer for emissions monitoring; and more

60 **Show Preview: AchemAsia 2019**
The AchemAsia exhibition and conference will take place May 21–23 in Shanghai, China

Departments

5 **Editor's Page** **Taking a stand on sustainability**
Sustainability issues, including climate policy positions, are key drivers for investment portfolios and corporate growth

84 **Economic Indicators**

Advertisers

64 **Hot Products**

69 **Gulf Coast Special Advertising Section**

81 **Classified**

82 **Subscription and Sales Representative Information**

83 **Ad Index**

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Cover design: Rob Hudgins

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ADVERTISING REQUESTS: SEE P. 82

Editor's Page

Taking a stand on sustainability

Last month, Royal Dutch Shell (The Hague, the Netherlands; www.shell.com) released a report[1] that assesses the company's alignment with 19 industry associations on climate-related policy. In the report, Shell CEO Ben van Beurden states "The need for urgent action in response to climate change has become ever more obvious since the signing of the Paris Agreement in 2015. As a result, society's expectations in this area have changed, and Shell's views have also evolved."

The report outlines four key policy positions that were evaluated: support of the Paris Agreement goals on climate change; government-led carbon pricing mechanisms; low-carbon technology policy; and the role of natural gas for energy. Of the 19 industry associations evaluated, Shell found that it was aligned with nine of them, had some misalignment with another nine, and had "material misalignment" with one, the American Fuel & Petrochemical Manufacturers (AFPM). Due to this misalignment with climate-related policy positions, Shell stated that it will not renew its AFPM membership next year.

Sustainable investing

As Van Beurden stated, expectations around sustainability issues, including climate change policy, have changed, and they are strong. Asset management firm BlackRock (www.blackrock.com) has seen a "surge in clients' interest in incorporating sustainability-related insights into their investments." Factors including environmental, social and governance (ESG) are now commonly tracked and evaluated for investments. BlackRock says that sustainable portfolios can be created without compromising financial goals, and in fact, suggests that ESG-friendly portfolios could be more resilient in downturns.

A report by Morgan Stanley Institute for Sustainable Investing and Bloomberg[2] that includes results from a survey of 300 respondents at U.S. asset-management firms, says that sustainable investing has indeed gone mainstream and is no longer a niche market. It further suggests that sustainability is a good investment: "Asset managers surveyed overwhelmingly agree that strong corporate ESG practices can potentially lead to higher company profitability and that companies with such practices may be better long-term investments."

Sustainability as a core value

A look at the websites of major chemical process industries (CPI) companies reveals that most, if not all, have a sustainability-related statement. For example, BASF SE (www.basf.com) says "Sustainability is at the core of what we do, a driver for growth as well as an element of our risk management." And SABIC's (www.sabic.com) website states "SABIC recognizes that in order to succeed in today's global marketplace, sustainability must be embedded in the way we do business."

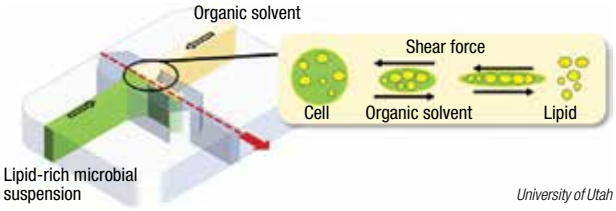
The need to incorporate sustainable practices in industry is clearly understood, but this changing landscape presents challenges that need to be tackled on various fronts. For more insight on some of these challenges for petroleum refiners, see the Newsfront in this issue, "U.S. Refiners Reckon with Uncertain Energy Future" (pp. 14–17). ■

Dorothy Lozowski, Editorial Director

1. Industry Associations Climate Review, www.shell.com/sustainability/transparency/public-advocacy-and-political-activity
2. Sustainable Signals: Growth and Opportunity in Asset Management, www.morganstanley.com/assets/pdfs/2415532_Sustainable_Signals_Asset_Mgmt_L.pdf

Impinging jet mixers are applied to bio-crude harvesting from algae

Microalgae have been investigated as a source of "bio-crude" — fatty acid molecules (lipids) that can be refined into renewable transportation fuels — but harvesting lipids from the algae cells economically remains the most challenging and energy-intensive step in the process. A common method for harvesting lipids involves drying the algae, then grinding the cells and dissolving the lipids with a blend of strong solvents. Now, researchers from the University of Utah (Salt Lake City; www.utah.edu) have developed a new harvesting method that eliminates the need for drying and grinding, potentially allowing a lower-energy harvesting process.



University of Utah

The new method adapts confined impinging jet mixers (CIJMs) for the first time to the task of stretching and breaking the algae cell walls and extracting cell contents. Inside a CIJM, jets of microalgae slurry collide with jets of organic solvent (hexanes) at high flowrates (1,200 mL/min), such that extreme local turbulence is created. The turbulence generates shear forces capable of rupturing algae cell walls (diagram). The lipids that are liberated in this way are dissolved by the solvent for further processing.

In adapting the CIJMs to microalgae harvesting, the research team determined the appropriate size of the reactor where the slurry and solvent are mixed, explains Swomitra Mohanty, University of Utah chemical engineering professor and research co-leader. "Also, we had to characterize the correct flowrates and determine the solvent-to-algae biomass ratio to create a working process," he says.

"Our research is really looking for a pathway to energy parity in algae biofuels — that is, we want to establish a method of extracting more energy from the algae than is needed to harvest it," Mohanty says. "The CIJMs enable a process that can use algae slurry directly, rather than requiring energy to remove the water and grind the biomass, and this allows significant energy savings."

The CIJM extraction process has been demonstrated at the bench scale, and the team is exploring industrial partnerships for scaling up the technology.

Enzyme engineering enables bio-based hydrogen peroxide

Borne out of a cancer research project at Massachusetts Institute of Technology (Cambridge; www.mit.edu), a new enzymatic process technology can co-produce gluconic acid and hydrogen peroxide without the safety risks and complexity of typical large-scale peroxide-manufacturing processes. Solugen Inc. (Houston; www.solugen.com) has engineered an enzyme that is extremely stable in the highly oxidizing environment required for H_2O_2 generation.

According to Sean Hunt, chief technology officer of Solugen, typical enzymes will rapidly denature in the presence of 0.1 wt.% H_2O_2, but Solugen's enzyme can retain its stability and activity in 10 wt.% H_2O_2 for weeks at a time. "On the process technology side, we are making organic acids and co-producing hydrogen peroxide. No other process technology does that," he adds. Since gluconic acid is typically produced in batch fermentation processes, Solugen's continuous process brings additional economic benefits. Eventually, Solugen wants to further fine-tune its enzyme to co-produce acetic acid along with H_2O_2.

Hunt says that the enzyme can be mass produced, enabling rapid scaleup of the technology. The first iteration of the technology was a manual, 7-gal bubble-column reactor that underwent a tenfold scaleup to an automated pilot plant, which started up in April 2018. At the 100-ton/yr pilot plant, corn syrup is continuously converted into H_2O_2 and gluconic acid. "We ship out multiple totes per week of product from the pilot plant," says Hunt. Now, Solugen is setting its sights on providing bio-peroxide for water-treatment applications in the upstream oil-and-gas sector with its first commercial plant. Located in Houston, the 10,000-ton/yr plant is slated to begin construction this summer, with completion expected in the first quarter of 2020.

Edited by:
Gerald Ondrey

DEPOLYMERIZATION

Last month, DuPont Teijin Films Ltd. (DTF; Contern, Luxembourg; www.dupont-teijinfilms.com) launched its new LuxCR depolymerization process, which upcycles post-consumer waste into a variety of biaxially oriented polyethylene terephthalate (BOPET) films. The LuxCR process depolymerizes mechanically recovered PET flake back into the monomer unit bis(2-hydroxyethylterephthalate) (BHET), which is chemically indistinguishable from virgin monomer. This base monomer is then repolymerized into a polyester polymer that is subsequently converted into a wide range of BOPET films. Contamination is removed during the process through a combination of monomer and polymer filtration units and by vacuum extraction which runs for several hours at temperatures between 270 and 300°C.

Initial commercial launches are planned in Q2 of 2019 across a range of packaging formats and will include high-temperature food-contact applications, such as ready-meal lidding and ovenable flow-wrap structures. Although the initial focus for the LuxCR process is to provide a feedstock to DTF's own film-manufacturing lines, feasibility studies are underway to see if the scope can be extended to include the external sale of polymer, which would open up the technology to applications such as PET bottles and trays.

'GLASS' FROM WOOD

Researchers from KTH Royal Inst. of Technology (Stockholm, Sweden; www.kth.se) have developed a window material made of wood that regulates how much heat can pass. To make the windows, a wood composite made from silver birch trees

(Continues on p. 8)

is first stripped of its lignin (the major light-absorbing component in wood), leaving behind empty porous spaces that are then filled with a polymer that matches the wood's refractive index so that light propagates through the material. The self-regulating thermal properties come from the addition of a phase-change material (PCM), which is capable of storing and releasing large amounts of heat. The KTH team used polyethylene glycol (PEG), a non-toxic biodegradable PCM. The solid-liquid transition temperature can be tuned by adjusting the molecular weight of the PEG. Leaking during the melting phase has been found to be unproblematic, due to the "strong scaffold of empty micro- and nano-scale pores" in the delignified wood.

MAKING ALGAE WORK

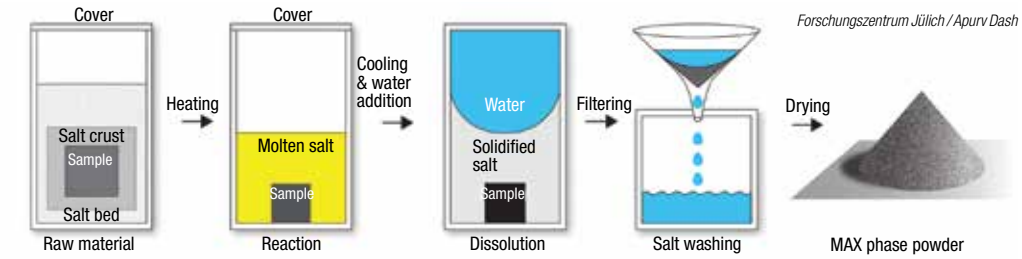
Solvay S.A. (Brussels, Belgium; www.solvay.com) Peroxides' plant in Portugal has partnered with a local biotech company for the on-site production of microalgae that will capture the equivalent of all its CO_2 emissions. The Algatec Eco Business Park project (algatec.eu/eco-business-park) has been designed to produce and harvest microalgae for various products and applications, while capturing CO_2. The biotech company Algae for Future (A4F; www.a4f.pt) and investor LusoAmoreiras initiated this project, which is under development at Solvay's Peroxides site in Póvoa, Portugal.

Algatec is currently exploring an initial area of 4,000 m^2, which corresponds to about 30 m^3 of culture of a species of microalgae called *Nannochloropsis*. When the project is completed in August 2020, the 14-hectare production area, microbiology laboratory and industrial biorefinery will become the largest microalgae-production platform in Europe.

After the initial culture and an intermediate stage of growth and concentration in the Algatec laboratory, the microalgae are transferred to "green walls" located on the industrial site — 50 flat panels, each 20 m long — where they find the right con-

(Continues on p. 10)

Protecting oxidation-prone materials with a crust of salt



Forschungszentrum Jülich / Apurv Dash

High-temperature synthesis of ceramics and other materials normally requires a cost-intensive inerting atmosphere to prevent oxidation. Now, researchers from Forschungszentrum Jülich (Germany; www.fz-juelich.de) have developed a process — the molten salt shielded synthesis/sintering (MS^3) process — that used molten salts as both a reaction medium and to protect ceramic powders from oxidizing during high-temperature processing in air. Synthesis temperatures are also reduced, and the final product is a highly pure, fine and loose powder that requires no additional milling.

Described in a recent issue of *Nature Materials*, the MS^3 process (diagram) has been used for the synthesis of so-called MAX phases, which are ternary transition metal compounds that combine properties of both ceramics and metals — heat resistant and lightweight like ceramics, yet less brittle, enabling them to be deformed like metals. MAX phases are also the building blocks for MXenes — compounds that are similar to graphene and have "extraordinary" electronic properties. These relatively new materials have potential applications in turbines, aircraft and aerospace and medical implants, but making MAX phase powders at the industrial scale has not been possible before.

MAX phases are produced at temperatures above 1,000°C. With MS^3, the precursors are first encapsulated with potassium bromide salt, which melts during the production process. The molten KBr protects the material from oxidation — no inert gas or vacuum is required. The salt also prevents the components from agglomerating, resulting in a fine powder. After processing, the salt can simply be washed off with water.

The process has been shown to produce a variety of MAX phases, such as Ti_3SiC_2[3], Ti_2AlN_4, $MoAlB_5$), as well as binary carbides (TiC) and for the sintering of titanium.

Converting CO_2 to carbon at mild conditions

An international research team led by RMIT University (Melbourne, Australia; www.rmit.edu.au) has developed a technique that can efficiently convert CO_2 from a gas into solid particles of carbon. The team included researchers from the University of Münster (Germany), Nanjing University of Aeronautics and Astronautics (China), North Carolina State University (Raleigh), University of New South Wales (Sydney, Australia), the University of Wollongong (Wollongong, Australia), and Monash University (Melbourne, Australia).

The storage of CO_2, either in its gaseous state or compressed into a liquid, has proved challenging and costly. Therefore, converting CO_2 into a solid offers an attractive alternative method for safely and permanently removing CO_2 from the atmosphere.

To date, CO_2 has only been converted into a solid at extremely high temperatures, making it industrially unviable. The team created a liquid metal electrocatalyst that contains metallic elemental cerium nanoparticles, which facilitate the reduction of CO_2 to layered solid carbon, at a low onset potential of –310 mV. The formation of a cerium oxide catalyst at the liquid metal/electrolyte interface, together with cerium nanoparticles, promoted the room-temperature reduction of CO_2. The electrode proved remarkably resistant to deactivation via coking caused by the solid carbon.

An extra benefit of the team's process is that the carbon can hold electric charge, making it a supercapacitor. The process also produces synthetic fuel as a by-product. The research was conducted at RMIT's MicroNano Research Facility and the RMIT Microscopy and Microanalysis Facility, with lead investigator, professor Kourosh Kalantar-Zadeh.

This process improves blends of starch-based plastic with conventional polyolefins

Thermoplastic starch, a biodegradable polysaccharide, is an attractive material for environmentally friendly plastics, but its cost and molecular properties have prevented it from being used in thin films. A process for a new starch plastic resin allows the material to be blended with conventional plastics to produce high-quality, high-strength plastic films.

BioLogiQ (Idaho Falls, Idaho; www.biologiq.com) has introduced NuPlastiq, a biodegradable plastic resin produced from waste starch at potato-cutting facilities (for French fries and potato chips). When blended with conventional polyethylene resins, NuPlastiq allows thinner films with the same strength.

Starch is made of amylose, a linear polysaccharide molecule, and amylopectin, which has a highly branched structure that limits its ability to form strong films. BioLogiQ has developed a proprietary process that creates a smaller particle size in the starch powder and removes the material's affinity for moisture. The modified starch powder is then made into a thermoplastic resin. The BioLogiQ process overcomes the problems created by the branched amylopectin structure, and allows the resulting resin to form strong films.

"To make blends traditionally, starch powder would be blended with conventional polyolefin resin pellets directly using a twin-screw compounding machine," says Brad LaPray, president of BioLogiQ. "We are making the starch into low-moisture resin pellets that can be mixed with conventional resins in existing production facilities."

When mixed with linear low-density polyethylene (LLDPE), NuPlastiQ allows films as thin as 2.5 microns to be produced, the company says. By displacing some conventional plastic and forming thinner films with equivalent strength, the blends reduce net greenhouse gas emissions and may improve the performance of recycling low-value plastic streams.

BioLogiQ recently announced a collaboration with Dow Packaging and Specialty Plastics (Midland, Mich.; www.dow.com) that is evaluating which potential thin-film and packaging applications would benefit from using blends of NuPlastiq and conventional Dow resins. "The plastics and packaging industries are looking for additional ways to increase sustainability, and these blends can be another tool in the toolbox," says Heather Turner, associate marketing director at Dow.

ditions for growth, such as sun exposure, CO_2 and optimized culture media (water and nutrients). Then, the microalgae will be harvested by filtration and centrifugation, producing a significant volume of high-value biomass. Microalgae species are a rich source of nutrients, such as lipids (omega-3 polyunsaturated fatty acids), proteins, antioxidants and vitamins. They represent an emerging sustainable opportunity, either as a source of raw material, or as final products in a rapidly increasing global market for food, animal feed, cosmetics, pharmaceuticals, bio-fibers, fertilizers, wastewater treatment, soil remediation and biofuels.

BIO-BASED JET FUEL

Scientists in China have developed a process for converting waste biomass (mostly cellulose that forms the cell walls of plants) from agriculture and timber harvesting into high-density aviation fuel. While chain alkanes have been previously derived from cellulose for use in jet fuel, the scientists believe theirs is the first study to produce more complex polycycloalkane compounds.

An author of the study,

(Continues on p. 11)

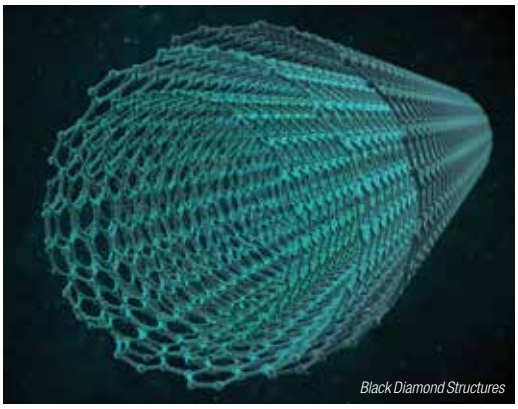
Process improves usefulness of CNTs for battery applications

Carbon nanotubes (CNTs) have been touted as game-changing nanomaterials in a wide variety of areas, but their actual commercial success has been less than expected thus far. To a large extent, the difficulty has centered around the tendency of CNTs to agglomerate and entangle, which limits their ability to provide the expected mechanical and electrical properties.

Now, a process developed by Black Diamond Structures (BDS; Austin, Tex.; www.blackdiamond-structures.com) offers a way to disperse the clumped CNTs so their favorable properties can be exploited in real-world applications. The process involves both chemical and physical manipulation of commercially available CNTs, such that the agglomerations separate and remain dispersed enough to be used in electrodes for lead-acid and lithium-ion batteries.

"Under an SEM [scanning electron microscope], CNTs appear clumped, like a cotton ball," says BDS CEO John Hacskaylo. "We developed a commercial-scale process that breaks apart the CNT clumps into individual tubes [see image], so they can exhibit their useful properties in real products."

Beginning with commercial CNTs, the BDS process involves a proprietary method to chemically functionalize the surface of the CNTs, and specially designed devices that mechanically separate the CNT agglomerates. The resulting products, trademarked as Molecular Rebar, are aqueous dispersions of separated CNTs that can distribute evenly into battery electrode materials.


Black Diamond Structures

When incorporated into electrodes, Molecular Rebar products have advantages for both lead-acid and lithium-ion batteries in both motor-vehicle and stationary-energy-storage applications. For lead-acid batteries, CNT-infused anodes help lengthen battery lifetime, increase charging speed and reduce the amount of lead required (lowering cost). For new-generation Li-ion batteries, adding Molecular Rebar in the higher-performing silicon anodes strengthens the material so it can withstand the swelling and shrinkage that occurs with the Si anodes.

BDS was formed through a joint venture between Molecular Rebar Design LLC (Austin, Tex.; www.molecularrebar.com) and SABIC (Riyadh, Saudi Arabia; www.sabic.com). SABIC recently announced that it has taken the majority stake in BDS for SABIC's specialty business to further strengthen its offerings for mobility electrification.

Nano-coated salts for energy storage

A new energy-storage process has begun operations at a large-scale pilot plant in Berlin, Germany. At the combined heat and power (CHP) facility of Swedish energy company Vattenfall, SaltX Technology AB (Hägersten, Sweden; www.saltxtechnology.com) constructed one 0.5-MW/10-MWh energy-storage unit using the company's patented nano-coated salt (NCS) technology.

"SaltX technology stores energy in inexpensive, highly available salt and subsequently recovers it in the form of heat or cold. The energy is stored chemically by separating salt from water and then released by combining them again," explains Eric Jacobson, head of growth at SaltX. Although this process is achievable with conventional salt, Jacobson explains that the cycle can only be performed a few times before the salt crystals agglomerate and prevent an effective chemical reaction from occurring. SaltX addressed this problem through its patented nano-coating, which allows energy to be charged and discharged thousands of times. After "charging" at 500°C, the NCS can store energy at room temperature for hours, days or months. "Furthermore, the nano-coating provides additional benefits in that it is non-corrosive, unlike regular salts, and is also non-toxic and recyclable," adds Jacobson.

According to SaltX, the NCS-based systems can achieve 90% efficiency, depending on the temperature differential — a larger temperature differential enables more useful heat transfer. The high energy density of NCS makes the units compact for installation into existing facilities. The system consists of just two storage tanks, one discharger and one charger.

To manufacture NCS at a large scale, SaltX has partnered with Wacker Chemie AG (Munich, Germany) and limestone processor Nordkalk Corp. (Pargas, Finland). Wacker is contributing the silica-based coating materials, while Nordkalk will process the salt, which mainly consists of calcium oxide. The partners plan to initially produce 10,000 tons of NCS. For the Vattenfall project, they have manufactured 25 tons of NCS.

A low-temperature catalyst for dry methane reforming

A catalyst that performs low-temperature reforming of methane with carbon dioxide (dry reforming) into synthesis gas (syngas) has been developed by Japanese researchers, led by Hideki Abe at the National Institute for Materials Science (NIMS, Tsukuba City, www.nims.go.jp), in collaboration with scientists from the Kochi University of Technology and Tokyo Institute of Technology.

Traditional steam-methane reforming requires high (more than 1,073K) temperatures to suppress carbon deposition, and is thus energy intensive (generating significant CO_2 emissions) while suffering from rapid catalyst degradation. Although dry reforming has the potential to reduce CO_2 emissions, it is also prone to carbon deposition, especially at lower temperatures.

The researchers have undertaken a catalyst-design strategy that precludes carbon deposition, by tailoring the 3-D topology of metal/oxide nanocomposites. The catalyst consists of an entangled network of fibrous phases of Ni metal and oxygen-deficient Y_2O_3 to form a rooted structure, designated as Ni#Y_2O_3. They demonstrated that the Ni#Y_2O_3 catalyst can activate CO_2 and CH_4 at 623K, and stably promote low-temperature dry reforming at 723K for over 1,000 h — ten times longer than traditional supported catalysts, such as Ni/Al_2O_3 and Ni/Y_2O_3. The increased stability is attributed to the Ni catalyst center of the Ni#Y_2O_3 being "topologically immobilized" by the oxygen-deficient Y_2O_3 matrix, which can eliminate carbon by-products. The new catalyst and its synthesis is described in a recent issue of the Royal Society's *Chemical Science*. ■

Ning Li, of the Dalian Institute of Chemical Physics of the Chinese Academy of Sciences (Dalian, China; www.dicp.cas.cn), believes this new biofuel is important for mitigating CO_2 emissions because it is derived from biomass and has higher density (volumetric heat values) compared with conventional aviation fuels. "As we know, the utilization of high-density aviation fuel can significantly increase the range and payload of aircraft without changing the volume of oil in the tank," he says.

To produce this biofuel, the scientists found that cellulose can be selectively converted to 2,5-hexanedione by hydrogenolysis. The 5-methylfurfural in the hydrogenolysis product is then converted to additional 2,5-hexanedione. Hydrogen is then reacted with the 2,5-hexanedione to obtain the final product — a mixture of C12 and C18 polycycloalkanes with a low freezing point and a density about 10% higher than that of conventional fuels.

Li and his team believe their process' cheap and abundant cellulose feedstock, fewer production steps, and lower energy cost and consumption mean it will soon be ready for commercial use. The biggest issue holding the process back is its use of dichloromethane to break down cellulose into 2,5-hexanedione. Dichloromethane, traditionally used as a solvent in paint removers, is an environmental and health hazard. The researchers are now working to find an environmentally friendly and renewable organic solvent that can replace the dichloromethane. ❐

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VENATOR

Plant Watch

Arkema starts up photocure resin expansion in China

April 11, 2019 — Arkema (Colombes, France; www.arkema.com) started up the 30% capacity extension of its photocure liquid-resin production plant in Nansha, located near Canton, China. This new production line will support the electronics, 3-D printing, adhesives and printing markets.

BASF to expand production capacity for sodium methylate in Brazil

April 9, 2019 — BASF SE (Ludwigshafen, Germany; www.basf.com) will increase the production capacity for its sodium methylate plant in Guaratinguetá, Brazil. The nameplate capacity will increase by 30%, from 60,000 to 80,000 metric tons per year (m.t./yr). The new capacity will come onstream in 2020.

Evonik to expand production capacity for transparent polyamides

April 8, 2019 — Evonik Industries AG (Essen, Germany; www.evonik.com) is expanding its production of transparent polyamides in Marl, Germany. The expansion is scheduled for completion in the first quarter of 2020. The company will be expanding production in part through targeted debottlenecking efforts and comprehensive optimization initiatives.

Nouryon expands chloromethanes production in Frankfurt

April 5, 2019 — Nouryon (Amsterdam, the Netherlands; www.nouryon.com) is further increasing capacity for chloromethanes at its site in Frankfurt am Main, Germany. The expansion is expected to be completed in 2020. The company first increased chloromethanes production in Frankfurt in 2017. The new project will increase annual production capacity of the chloromethane methyl chloride by over 30%.

Borealis starts up compounding plant in North Carolina

April 3, 2019 — Borealis Group's (Vienna, Austria; www.borealisgroup.com) new compounding plant in Taylorsville, North Carolina has come on stream. The new plant features dedicated production lines for thermoplastic olefin and short glass fibers and adds 30,000 m.t. to Borealis' global polypropylene compounding capacity.

ExxonMobil invests in significant expansion in Singapore

April 2, 2019 — Exxon Mobil Corp. (Irving, Tex.; www.exxonmobil.com) has made a final investment decision on a multi-billion-dollar expansion of its integrated manufacturing complex in Singapore. The investment will add 20,000 bbl/d of lube base stocks capacity.

Solvay to raise hydroquinone capacity in Europe by 20%

March 28, 2019 — Solvay S.A. (Brussels, Belgium; www.solvay.com) is raising its European production of hydroquinone by 20%. The capacity expansion at Solvay's plant in Saint-Fons, France is accomplished by debottlenecking the existing unit and follows a recent capacity increase in Zhenjiang, China. The plant should be fully operational during the second quarter of 2019.

Fluor begins FEED work on Invista's new adiponitrile plant in China

March 26, 2019 — Fluor Corp. (Irving, Tex.; www.fluor.com) has started the front-end engineering and design (FEED) work for Invista's (Wichita, Kan.; www.invista.com) new adiponitrile (ADN) manufacturing facility in China. The plant is anticipated to have a production capacity of approximately 400,000 m.t./yr of ADN.

Ineos to double planned capacity of U.S. Gulf Coast ethylene oxide plant

March 25, 2019 — Ineos (London; www.ineos.com) is to double the size of its planned ethylene oxide (EO) and ethylene oxide derivatives (EOD) facility to be built on the U.S. Gulf Coast. The new plant is now expected to produce around 520,000 m.t./yr of EO and EOD. The plant is expected to be operational in 2023.

Sibur begins production of DOTP at Perm site

March 25, 2019 — Sibur (Moscow; www.sibur.com) produced the first batch of dioctyl terephthalate (DOTP) at its recently commissioned facility in Perm, Russia, which is Europe's largest production site of its kind, with capability to produce 100,000 m.t./yr of DOTP.

Lubrizol further expands TPU capacity with new production line in China

March 20, 2019 — The Lubrizol Corp. (Cleveland, Ohio; www.lubrizol.com) began operations at a new thermoplastic polyurethane (TPU) production line at its Songjiang, China plant. This considerable expansion of the Songjiang plant follows the launch last year of a new compounding line at the site.

Kraton to construct a latex manufacturing unit in Brazil

March 19, 2019 — Kraton Corp. (Houston; www.kraton.com) plans to build a semi-works latex production unit in Paulinia, Brazil. Construction

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is scheduled to be complete by the first quarter of 2020, with commissioning taking place later in the year.

Mergers & Acquisitions

Tronox completes acquisition of Cristal

April 11, 2019 — Tronox Holdings plc (Stamford, Conn.; www.tronox.com) completed its acquisition of the TiO_2 business of National Titanium Dioxide Co. (Cristal; Jeddah, Saudi Arabia; www.cristal.com). In previous transactions, Cristal divested its North American TiO_2 business to Ineos, and Tronox divested its European TiO_2 paper-laminate business to Venator Materials plc (Wynyard, U.K.; www.venatorcorp.com).

Ube Industries acquires resin compounding company in Spain

April 9, 2019 — Ube Industries, Ltd. (Ube; Tokyo, Japan; www.ube-ind.co.jp) has acquired Spanish compound manufacturer Repol S.L. Repol operates a compound business using nylon 6, nylon 6,6, polypropylene, polyacetal and other resin raw materials. Additionally, Repol's recycling technologies are anticipated to be an asset to Ube's future business development.

Eastman acquires Marlotherm business unit from Sasol

April 2, 2019 — Eastman Chemical Co. (Kingsport, Tenn.; www.eastman.com) has acquired Sasol Ltd.'s (Johannesburg, South Africa; www.sasol.co.za) Marlotherm heat-transfer-fluids manufacturing assets, located in Germany, and related formulations, intellectual property and customer contracts. This new product line will become a part of Eastman's Specialty Fluids business.

Saudi Aramco invests $69 billion to acquire majority stake in SABIC

March 27, 2019 — Saudi Aramco (Dhahran, Saudi Arabia; www.saudiaramco.com) signed a share-purchase agreement to acquire a 70% stake in The Saudi Basic Industries Corp. (Sabic; Riyadh; www.sabic.com) from the Public Investment Fund of Saudi Arabia in a transaction worth $69.1 billion. In 2018, Sabic's production volume across its various business units was 75 million m.t., with recorded net income of $5.7 billion.

Covestro and Genomatica partner for sustainable growth

March 27, 2019 — Covestro AG (Leverkusen, Germany; www.covestro.com) and Genomatica (San Diego, Calif.; www.genomatica.com) have formed a partnership to develop high-performance materials from renewable feedstocks. This longterm partnership involves both companies working to drive commercially focused projects aimed at reducing the use of fossil fuels.

Evonik merges methacrylate monomers activities

March 19, 2019 — Evonik is merging its specialty methacrylate-monomers product line with its oil additives business to become the new Oil Additives business line. The monomers unit was formerly part of Evonik's Methacrylate business, which is in the process of being sold to U.S.-based private-equity firm Advent International. ■

Mary Page Bailey

U.S. Refiners Reckon with Uncertain Energy Future

Many indicators point to current success and prosperity for U.S. petroleum refineries, but simultaneously, the industry is facing a future of massive changes in energy and transportation

IN BRIEF

REFINING IN A LOW-CARBON FUTURE
POLITICAL ENGAGEMENT
TRANSPORTATION CHANGES
PETROCHEMICAL FUTURE

By many measures, the U.S. petroleum-refining industry is succeeding and prospering. According to the American Fuel and Petrochemical Manufacturers (AFPM; Washington, D.C.; www.afpm.org), U.S. refining capacity topped 18.6 million barrels per day (bbl/d), and capacity utilization averaged over 93% last year, and the U.S. has become a net exporter of refined products. AFPM president and CEO Chet Thompson struck an optimistic tone to open the 2019 AFPM Annual Meeting in March in San Antonio, saying that the state of the petroleum refining industry is strong and touting the industry's safety record and reduced emissions, but also warning that the industry's "continued success is not guaranteed."

Even as the petroleum refining industry thrives in the near term, it is being forced to reckon with a long-term future in which power generation and transportation may look dramatically different than they have in past decades. The environmental and climate externalities associated with the burning of fossil fuels have forced the world to find ways to lower carbon emissions, increasing pressure to move toward renewable energy sources, electrification of the transportation fleet and an embrace of circular economy concepts. Large-scale changes to the transportation fuel and energy system are costly and complicated, so they will take time. But trends in these areas are already forcing refiners to change the way they approach their businesses and manufacturing, and the product slate they offer. Many of these issues were explored at the recent AFPM Annual Meeting, where the theme revolved around sustaining the future of the petroleum refining industry.

Refining in a low-carbon future

Framing the issues concerning the future of petroleum refining are a relatively understudied, but crucially important, set of questions about how to manage a drastic reduction in carbon dioxide (and other greenhouse gases) emissions to avoid the worst effects of climate change, while still realizing benefits from petroleum products that do not have non-fossil-fuel alternatives. Two researchers that have been exploring these questions are Deborah Gordon, senior fellow at the Watson Institute for International and Public Affairs at Brown University (Providence, R.I.; watson.brown.edu) and Madhav Acharya, a technology-to-market advisor at the U.S. Department of Energy's Advanced Research Projects Agency-Energy (ARPA-E; Washington, D.C.; arpa-e.energy.gov).

In a recent interview, Acharya observed that, to date, efforts aimed at de-carbonizing the economy have been approached largely in a patchwork fashion, without sufficient consideration of the interplay among all the sectors of the economy.

"By making shifts in one part of the economy, you will inadvertently upset the balance that has existed for the past century, which could bring about some interesting dilemmas," he says. As a case in point, he asks, "how do you achieve a situation where gasoline as a fuel is phased out, but lubricants (to run wind turbines, for example) are still necessary? Today, they are made at the same facility, so how do you achieve that?"

The question is, Gordon says, "under the constraints of climate change, how can we re-draw the refining roadmap to manufacture net-zero-emission products while shrinking the refining sector's carbon footprint? Although the future energy supply mix is not expected to resemble the past, we are still going to need sulfur for many chemical products, asphalt and jet fuel, which are not easily replaced by non-fossil-fuel alternatives. But do we really need high-carbon petroleum coke and heavy residual fuels?"

The refining industry, and society as a whole, will have to reckon with the fact that dozens of products are produced from crude petroleum, some of which, such as gasoline and diesel, are facing declining demand, while others, such as *para*-xylene and propylene, will see increased demand. Such an end state, where some petroleum products are devalued, while others remain necessary, is not feasible given how refineries are configured and operated today, Acharya says. "Either new pathways will have to be devised [to produce] all the other byproducts, or their price will go up as refiners have to absorb the cost of making fuels that can no longer be sold."

A short-term response to this is the emergence of "crude-to-chemicals" plants, where a greater portion of the barrel (~50%) is converted into higher-value petrochemical feedstock. "Crude to chemicals is designed to make specific refineries more profitable. However, it still falls short in the long run, as far as producing a tailored product slate needed for a low-carbon economy," says Acharya.

"We need to think about the energy transition toward low or zero carbon holistically — it cannot be achieved by first decarbonizing electricity generation, and then moving to other sectors," Acharya says. "Most pathways to deep decarbonization gloss over how challenging it will be, and leave it up to future innovation to solve the problem."

Last year, Acharya and Gordon outlined the practical realities — for both the refining industry and for society as a whole — associated with shifting toward renewable electricity generation, and electrified vehicles in a paper [*1*] for the Carnegie Endowment for International Peace (CEIP; Washington, D.C.; www.carnegieendowment.org), where Gordon is former director of the CEIP Energy and Climate Program.

Going forward, both Acharya and Gordon stressed the continued importance of the petroleum refining industry, but said large changes are likely because of the climate and environmental imperatives mentioned. "The refining sector also has not come to terms with a future where large parts of their product slate are valueless," Refineries might well become stranded in the same way as oil reserves, Acharya says.

FIGURE 1. A sophisticated policy approach will be needed for the oil supply chain to avoid negative unintended consequences

Gordon agrees: "Thinking holistically, how to transition the refining sector away from fossil fuels is an analytic question, one that must be modeled according to engineering, economic, and environmental constraints. What happens if society no longer needs a growing proportion of a refinery's products?"

The need for communication among all stakeholders is critical to work out how to manage the transition to a low-carbon economy and how to help each industry sector adapt. "We need a dialogue where all stakeholders are at the table and talk about the gaps in technology that need to be filled in to have a fully decarbonized economy, and how each sector can adapt to that new world," Acharya says.

Petroleum refining has to be part of every discussion, because it makes products that touch every other sector, even if that link is not evident at first glance," Acharya points out.

Gordon further comments: "petroleum refiners need to be at the table to help puzzle through the future of refining in a low-carbon world. A durable energy transition will require major modifications to the well-honed petroleum system. Refiners need to be a big part of the solution if we're going to completely de-carbonize our energy future." There will need to be a great deal of research support in this area, she adds.

In addition, the story must be global — the solution is not to electrify vehicles in wealthy nations and simply export displaced gasoline along with "dirtier" residual products to poorer countries, Gordon says. "We want a safer, better world overall, not only in certain places."

Political engagement

At the AFPM meeting, leadership spoke of engagement on climate-related policy questions, which have taken on renewed urgency over the past year. Although as an organization, AFPM has traditionally taken relatively conservative positions with regard to climate change, Thompson acknowledged that the industry needs to be involved with other stakeholders in looking ahead. "We have to continue to collaborate and do our part, along with other stakeholders, to find an appropriate path forward," he said. "Doing our part means ensuring we have a seat at the table. It means engaging in rational and balanced conversations about the value of our products to society and reasonable measures to address climate change."

Thompson also mentioned that the industry should continue its efforts in R&D of renewable diesel or algae-based fuels, and continuing the work in carbon capture and sequestration and further improving process efficiency and making products that promote efficiency in other

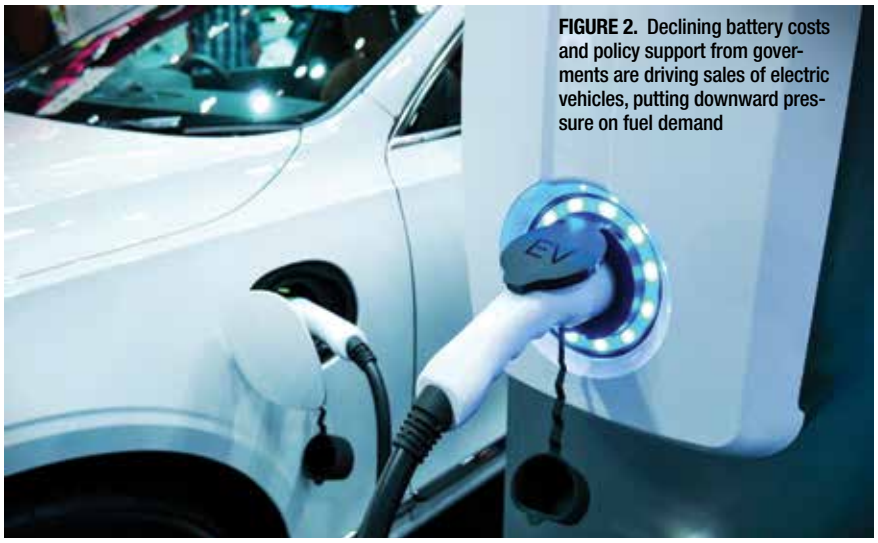

FIGURE 2. Declining battery costs and policy support from governments are driving sales of electric vehicles, putting downward pressure on fuel demand

systems. While Gordon agrees, she believes that the "industry needs to avoid 'greenwashing' by tinkering at the margins, when entirely new processes and capital are needed to make the necessary shifts a reality."

Mentions of climate change notwithstanding, Royal Dutch Shell (The Hague, the Netherlands; www.shell.com) recently left the membership organization reportedly over the fact that the company's views on climate change, renewable fuels and other policy areas did not align with AFPM's.

Several prominent research reports, including one late last year from 13 U.S. Federal Agencies, provide blunt warnings on the negative effects of climate change in areas from public health and human habitation to food security, biodiversity and economic activity. The situation is generating considerable political pressure to address the issue. Climate-related legislative proposals affecting energy and transportation are likely to be prominent political issues in years ahead (Figure 1).

Brown's Gordon commented that "if and when policy makers dial up the environmental pressure on the industry, they will have to adopt a sophisticated approach to the tightly-integrated oil supply chain, so we get the intended outcomes and don't cause unintended consequences."

At the AFPM annual meeting in March, AFPM's Thompson mentioned the "Green New Deal (GND)," a concept that has been discussed by environmental activists in past years but that has become widely known in 2019 as a set of (as yet undefined) policy ideas from Democratic lawmakers aimed at achieving net zero-CO_2 emissions and transitioning to carbon-neutral energy infrastructure. While Thompson criticized the GND as "unrealistic," he said the industry needs to take such initiatives seriously and engage the public, lawmakers and policy makers to communicate the far-reaching value of the industry, for fuels and a wide-ranging set of products that are essential to modern life. Initiatives such as the GND are elements of the new political reality and Thompson said would be a mistake for the industry to dismiss or ignore them.

For the moment, discussion of the GND is largely partisan and devoid of specific policy proposals. The GND failed to garner sufficient votes in a recent Senate procedural vote on a resolution to consider GND legislation, but the vote was protested by Democrats as a partisan attempt by Senate Republican leaders to force moderates to take a position on the issue, rather than a serious attempt to consider the ideas.

Transportation changes

Emerging changes in the transportation sector, and the effects that they will have for the refining industry, were a key topic at the AFPM meeting in March. Demand for liquid fuels in the developed world is facing serious headwinds — not necessarily in the near-term, but further into the future — from increasing fuel economy standards, pursuit of electric drivetrains, and forthcoming shifts away from personally owned cars to mobility-as-a-service models. The current business model of selling oil-powered cars to consumers for personal use will change dramatically in the future, according to Blake Eskew of IHS Markit Ltd. (London, U.K.; www.ihsmarkit.com). "Electric vehicle technology is advancing, with China as the leader in this area," Eskew says. Declining battery costs and policy support from governments are driving sales of EVs," he adds (Figure 2).

It will take time, however, and likely additional technology advancements in vehicle batteries, for the share of EVs to approach the share of internal-combustion-powered vehicles. In the meantime, fuel economy standards for existing internal-combustion engines will become more widespread and more stringent.

"In the coming years, 90% of new vehicles sold will be in countries with fuel economy standards," Eskew says.

Alan Gelder, vice president for refining, chemicals and oil markets at global energy consultancy Wood Mackenzie (Edinburgh, U.K.; www.woodmac.com) says that fuel efficiency standards for cars, along with others for commercial trucking, "serve to decouple demand for refined products from economic activity."

Petrochemical future

Analyst forecasts, such as that from Wood MacKenzie, expect petrochemical feedstocks to make up a growing portion of oil demand: from 13% in 2018 to 20% by 2035. Refining industry players are reacting by investing in production configurations that generate higher levels of petrochemical feedstock and lower levels of transportation fuels, especially gasoline and diesel.

Refinery-petrochemical integration (RPI) is becoming standard, and the model is evolving. In the traditional approach to refinery-petrochemical integration, the refinery arm of the business hands off materials to the petrochemicals arm, explains Stanley Carp, senior manager for configurations at Honeywell UOP (Des Plaines, Ill.; www.uop.com) "The movement is toward a model where

the two areas are acting as a single business unit — operating as a system, with integration of heat and utilities, rather than as two independent entities of the business." As refinery configurations change, Carp says the key is to look at petrochemicals as primary products at every new configuration, rather than as secondary to fuels.

The evolving model for RPI allows refining facilities to make up to 70% or more of petrochemical feedstocks, such as propylene and *para*-xylene, while making much smaller amounts of transportation fuels, as the forecast demand slip for gasoline and diesel and growth for petrochemicals takes hold. New facilities in China are minimizing fuel production and maximizing petrochemical production, Carp notes. Each configuration will differ, depending on which petrochemicals are desired and will depend heavily on geographical considerations.

In a talk at the AFPM meeting, Carp emphasized the importance of refinery flexibility as the expansion from refining into petrochemicals progresses. "Refiners need to be able to move where the market moves, and respond quickly to changing conditions — Don't design yourself out of the ability to make profits," he says. Digital connectedness is also an important aspect of the future refinery, Carp says. "How quickly can I turn process data into operational adjustments?" UOP suggested that it might be possible to design a plant where the entire crude stream is converted to chemicals.

Several recent examples highlight the petroleum refining industry's expansion of its current chemicals portfolio. In April, Saudi Aramco (Dharhan, Saudi Arabia; www.saudiaramco.com) announced the purchase of a controlling stake in SABIC (Saudi Basic Industries Corp.; Riyadh, Saudi Arabia; www.sabic.com). Aramco acquired 70% of SABIC from the current holder, the Public Investment Fund (PIF) of Saudi Arabia. The deal is valued at $69.1 billion for the 70% stake. The remaining 30% of SABIC is publicly traded on the Saudi stock exchange. Saudi Aramco has said it wants 3 million bbl/d of crude oil to be petrochemical-focused. The acquisition of SABIC can allow wider collaboration and avoid competition, as the two companies more recently have been overlapping into the natural positions of the two separate businesses, particularly around petrochemicals, Saudi Aramco says.

In China, Hengli Petrochemical Group recently completed its refinery and petrochemical complex near Dalian. The facility is geared toward flexible petrochemicals production, as well as fuel refining. The Zhejiang petrochemical project near Zhoushan is also starting up. Analysis by Wood MacKenzie anticipates a new wave of refining capacity in China in 2020, driven by several mega crude-to-chemicals projects.

For more on the issues discussed at the AFPM meeting, see the online version of this article at www.chemengonline.com for additional coverage of a panel discussion on the future challenges for the refining industry. ■

Scott Jenkins

Reference

1. Gordon, D. and Acharya, M., Oil Shake-up: Refining Transitions in a Low-carbon Economy, April 2018, https://carnegieendowment.org/2018/04/03/oil-shake-up-refining-transitions-in-low-carbon-economy-pub-75954

MANWAY

Smart Sensors Enable Industry 4.0

Coupled with advanced analytics and networking capabilities, today's smart sensors help processors optimize the facility

IN BRIEF

THE FUTURE OF INDUSTRY 4.0
THE CURRENT SITUATION
DRIVING TOWARD INDUSTRY 4.0
SENSORS: THE HEART OF INDUSTRY 4.0
NEW SMART SENSORS

Yokogawa

FIGURE 1. **"The key to Industry 4.0 is not just getting data, but taking this abundance of data and converting it into useful, understandable information that can be used to control the process and the business," says Yokogawa's Trygstad**

Picture a piece of equipment not just monitoring its own health, but also automatically ordering the part it requires and, when it notes that the part has been received, sending an alert to the maintenance technician to come fix it, while also providing detailed visual instructions on how to perform the repair virtually via a handheld device. Or, imagine management in a petroleum refinery using realtime data and information to determine, on the fly, whether they can take advantage of bargain-priced opportunity crude or low-cost natural gas to positively impact the profitability of the plant. Both these scenarios — and many others like them — portray the ultimate vision of Industry 4.0, and are the anticipated result of integration between machines and humans. Workers will be armed with realtime data that has been analyzed and contextualized to provide actionable information which can be used to positively impact the profitability of the process, facility or entire enterprise. And, at the heart of it all are smart sensors, which are evolving, alongside other technologies, such as data analytics and connectivity, to provide meaningful data to those who can use it to make well-informed business decisions.

The future of Industry 4.0

Whether you call it Industry 4.0, big data or the industrial internet of things (IIoT), the future undoubtedly includes the integration of ground-level data that can be shared with appropriate parties, from maintenance technicians all the way up to top-level management, and used to make decisions that impact the overall performance of the business, says Marcus Trygstad, consultant, Advanced Analytical Technology, with Yokogawa Corp. of America (Sugar Land, Tex.; www.yokogawa.com). "The key to Industry 4.0 is not just getting data, but taking this abundance of data and converting it into useful, understandable information that we can use to control the process and the business properly," says Trygstad. "We've had the ability to collect data for a long time, but what is changing is the quantity of data and the ability to transform it into actionable information at the same time as we are becoming more sophisticated in the use of machine learning, artificial intelligence and digitization. Once we begin to really integrate and harness all the information and technologies, the future of Industry 4.0 will include the integration of data and informed decision making from top to bottom in an organization" (Figure 1).

Gordon Bordelon, chemical industry lead, with Rockwell Automation (Milwaukee, Wis.; www.rockwellautomation.com) adds that this type of visibility will also allow chemical processors to become more responsive, which will be necessary to keep up with the competition in the future. "There is a massive amount of pressure on chemical processors to become more flexible and agile. They will need to make chemicals that are construed as more environmentally friendly or begin

sourcing more materials that are environmentally friendly in an effort to say they produce sustainable-based chemicals. Digitization helps create more flexible operations, allowing processors to produce different products on existing equipment and modify raw materials to meet sustainability goals, market demand and cost pressures."

Industry 4.0 is also being looked at as a means to gather more data out of the plant to assist with regulatory compliance. Bordelon continues, "Having smart sensors, analytics and digital data sharing via Industry 4.0 will allow management, in real time, to understand how they are performing from a sustainability and regulatory standpoint and get answers to questions like, 'What's my carbon footprint? What can we do to run more efficiently using fewer or different resources and have lower emissions with fewer releases?'"

Eric Heilveil, marketing manager for Process Instrumentation with Siemens (Harleysville, Pa.; www.siemens.com) summarizes these ideas. "The vision for Industry 4.0 includes a fully integrated organization from management down to engineering to operators and maintenance staff," he says. "The large data pond that they all swim in will be a single data hub or point of contact for the entire operation, from human resources to engineering to manufacturing and distribution, to ensure a very concise and consistent workflow that allows teams to work together at the same time to reach common goals rather than having each department work in isolation or in sequence."

The benefits of this are many. "This type of integration reduces the possibility of error created when just a single set of eyes is looking at it and provides a check and balance for perfection," explains Heilveil. "Time to market can also be reduced by the integrated workflow and it will provide a superior means to reducing quality issues and increasing accuracy while producing goods and distributing them using less energy while optimizing the use of human and raw material resources."

Pepperl+Fuchs

FIGURE 2. **Wilsen.sonic.level, a wireless sensor with integrated ultrasonic module for fill level detection, will be the first technology available in the U.S. this year from this line of IIoT-ready sensors**

The current situation

While intense and enterprise-wide integration is several years down the road for most processors, many are already beginning to embrace the technology on a smaller scale and reaping benefits. For instance, this type of information sharing is already assisting processors coping with a

NEW SMART SENSORS

Providers of smart sensors continue to innovate based on the needs of the chemical process industries, so product launches are happening frequently. Here's a roundup of the latest in the space.

Pepperl+Fuchs is launching a new IIoT-ready system, dubbed Wilsen. "The idea behind the Wilsen concept is that we provide sensors that are self-contained, battery-powered and can communicate via one of many networks," says the company's Hornis. "We can take one of these sensors, attach it to a tank in the middle of nowhere and, as long as there's a cell tower in the vicinity, transmit data." While there will be an entire family of Wilsen sensors, Wilsen. sonic.level, a wireless sensor with integrated ultrasonic module for fill level detection, will be the first technology available in the U.S. this year from this line (Figure 2).

Emerson recently launched a new Location Awareness system (Figure 3) that provides realtime, safety-focused monitoring of employees. Enabled by WirelessHART Anchors and battery-operated personnel and asset tags, the system includes geofencing, safety mustering and man-down alerts. "It allows management to understand where assets and people are in the plant at any given time to make sure that employees are safe and that management can send help if there's an issue," says Emerson's Karschnia.

Yokogawa recently announced the release of its Sencom Smart Adapter SA11 (Figure 4). The data gathered by the adapter, through an interface mechanism, can be uploaded to the cloud and used for optimization of plant operations, efficiency and asset management.

ABB Ability Digital Powertrain is a recently launched suite of digital solutions, including sensors, software and services, combining connectivity and data analytics (Figure 5). "The Digital Powertrain combines our existing sensing technologies for monitoring motors, bearings, pumps and drives all in the same portal where users can either analyze a particular element of the system or take a look from a high level at the complete powertrain," says ABB's Rdzanek.

Honeywell introduced the SmartLine Wireless Pressure Transmitter (Figure 6), which offers a flexible, scalable, secure and cost-effective solution for both pressure monitoring and control when combined with the company's wireless network technology. The OneWireless Network infrastructure supports two of the leading industrial wireless protocols — ISA100 Wireless and WirelessHART, providing flexibility when implementing wireless systems. ❑

Emerson

FIGURE 3. Enabled by WirelessHART Anchors and battery-operated personnel and asset tags, the Location Awareness system includes geofencing, safety mustering and man-down alerts

FIGURE 4. The data gathered by the Sencom Smart Adapter, through an interface mechanism, can be uploaded to the cloud and used for optimization of plant operations, efficiency and asset management

Yokogawa

retiring workforce, while initiating a new breed of millennial employees, says Asheesh Arora, vice president of the Field Instrument Business within Honeywell Process Solutions (Houston; www.honeywellprocess.com). "Industry 4.0 technologies allow us to capture information from the aging workforce while fulfilling the needs of the new millennials who would like to have data at their fingertips," he says. "Younger engineers want to spend time using available data rather than questioning what the data means. On the other side, we can capture the knowledge of the seasoned engineer, digitize and model it to provide knowledge to the new workforce before those industry veterans walk out the door."

Increased safety is another huge win currently available thanks to early Industry 4.0 capabilities. "Safety is a critical benefit of embracing 4.0 technology," says Artur Rdzanek, global product manager for Sensored Products with ABB Motors and Mechanical (Greenville, S.C.; www.abb.com). "Especially in a chemical plant, there can be dangerous equipment and processes where you don't want operators and maintenance staff going if they don't have to. Today's sensing technologies coupled with the ability to send information to computers and handheld devices reduces the amount of time that employees need to be in these hazardous locations, because they can check the data related to the machine or the process from the safety of their PC or device, as well as know what needs to be done before they enter the area when it does become necessary."

Today's available technologies are also being applied to improve maintenance. "The question we are regularly asked is: 'How can the value proposition of IIoT be implemented in daily maintenance and asset management?'" says Anupam Durani, BU manager sales and marketing for Analytical Instruments with Yokogawa Europe. "IIoT has the potential to have a dramatic effect in how maintenance is carried out. It can allow technicians to diagnose a device from any location and access the valuable information to troubleshoot and solve a problem. Operators can be notified immediately whenever an asset fails to operate within a normal range and receive all necessary instructions for returning the asset back into operation."

In a similar vain, Industry 4.0 is also shining in the arena of overall plant optimization. Rockwell's Bordelon says the technology is currently being used to improve product quality and asset utilization. "Today's connected chemical plants have an entirely new way of doing business. They know, in real time, when a process isn't where it needs to be or if there's a problem with equipment or unskilled operators causing quality issues. They have the data to support continuous improvement engagements and root cause analysis, as well as real-time alarms that tell them how to modify the process to remove the quality issue or safety concern. We call it asset utilization and by using digitization to optimize

equipment and processes, benefits like reduced downtime and improved product quality are being realized."

Bob Karschnia, vice president and general manager of Wireless for Emerson Automation Solutions (Shakopee, Minn.; www.emerson.com) agrees. "The premise of Industry 4.0 is using the available technologies — smart sensors, data analytics and connectivity — to improve operations. We already have the sensors and other technologies in place and are using them to give us the information we need to improve the efficiency of the plant, increase reliability of equipment and process, boost safety and reduce the environmental impact of the plant."

As an example, he points to monitoring the efficiency and reliability of heat exchangers — a common practice in today's process environments. "In a 250,000 barrel refinery, just by monitoring heat exchangers for efficiency and fouling via currently existing sensing and analytics technologies, it is very likely that they can save about $3 million a year between energy savings and maintenance costs, which provides a return on investment that can be measured in months."

Driving toward Industry 4.0

Most experts agree that implementation of currently available technologies in an effort to tackle current issues within the facility is the best way to start embracing Industry 4.0. "When we begin to help our customers optimize the performance of the plant, we ask what their consistent problems are across the plant or enterprise," says Karschnia. "We give our customers a list of equipment that we recommend starting with — about eight to ten possible applications, such as heat exchangers and steam traps, in which pervasive sensing provides tangible results — and then suggest building on the momentum of that success. In addition, it is often possible to use the success of the first application to pay for the next one and so on until, eventually, they all pay for themselves and it becomes almost self funding."

Honeywell's Arora agrees: "While the long-term goal of Industry 4.0 is a connected enterprise view, the practical approach to beginning the journey is to start with a sublevel or subsection view before attempting the end-to-end journey.

"We encourage our customers to sit down and talk about their current challenges, such as which units cause what problems and then begin to build an optimization model around one of those issues or units, using currently available data and technology to gather information and provide context around the data to help them improve that process or better use the asset," he explains. "Once that journey starts, we can identify the next challenge and add more sensors to more equipment until the entire organization is involved. And, the ultimate goal is that, eventually, all views come together in one place after they have been massaged, analyzed and personalized for each person who needs to see them."

Sensors: the heart of Industry 4.0

"The interesting part of this is that all the base technologies are already available," says Helge Hornis, technical director of Factory Automation with Pepperl+Fuchs

ABB

FIGURE 5. ABB Ability Digital Powertrain is a suite of digital solutions, including sensors, software and services, combining connectivity and data analytics

Americas (Twinsburg, Ohio; www.us.pepperl-fuchs.com). "We have sensors that are smart. We have ways to transfer information wirelessly. We have software with data analytics, artificial intelligence and machine learning. We have hardware to set up the necessary networks. We just need to put it all together and are really just waiting for the applications to be invented. This means it will be a swifter journey to this, the fourth industrial revolution, than to the previous ones because nothing needs to be invented to make it happen."

But at the very heart of it all is the increasingly smart sensor. "The phrase I like to use is that you can't manage what you cannot measure," says Siemens's Heilveil. "There is no improvement in process or product quality without measurement. There is no management without data that comes from a measurement, so this means instrumentation — the sensors and gadgets in the trenches doing the measuring — are key to Industry 4.0."

Yes, in addition to the sensors you need a way to move the data from the sensors (usually a gateway of some sort) to a location (often the cloud or a historian) for storage and number crunching via analytics and, of course, connectivity to move this now actionable data to the people who can use it for optimizing the process. "These are all necessary components and there isn't any one component that's more important than another, but, that being said, the process instruments and sensors are where the rubber hits the road. Just as you can't tell if someone has a temperature without a thermometer, you can't collect data without a sensor," says Heilveil.

So what's going on with today's smart sensors that is making data collection easier than ever? A lot. "We currently have high-quality data and sensors and the innovation continues, so I guess you could say we have 'smarter' smart sensors," says Honeywell's Arora. The first development, he says, is the combination of sensor measurements. "What we are seeing is there is much effort and expense required to install multiple sensors in places where there are constraints. In a location like an offshore platform, any one device saved, multiplied by hundreds, it is a gain. In a process plant, fewer numbers of sensors mean less tapping points and inserts into the piping. So we are seeing the development of sensors that can pull multiple measurements and provide data from one installation."

Another improvement is that more and more sensors are going to wireless, battery-powered technologies, says Emerson's Karschnia. "We have wireless, battery-operated transmitters that are driving toward non-intrusive measurements for almost everything, including pressure, temperature, level, flow corrosion monitoring, acoustic monitoring, gas sensing, electrical noise and so on. This allows users to connect them quickly and easily and at a much lower cost. This is the reason why people are able to add sensors more pervasively."

In addition, today's sensors offer a much richer array of options and opportunities to improve the process they are interfacing with, says Siemens's Heilveil. "They offer robust diagnostics, alarming features and safety functions. Some measure as many as four or six variables," he says. "If you take all of the diagnostics, safety functions and multivariable measurements and pair that up with robust digital protocols, it enables today's sensors to quickly and reliably provide critical and significant amounts of quality data, differentiating them from earlier sensors."

Honeywell

FIGURE 6. The SmartLine Wireless Pressure Transmitter offers a flexible, scalable, secure and cost-effective solution for both pressure monitoring and control

In the end, whether starting small with monitoring one piece of equipment or beginning on the journey to an integrated enterprise, embracing Industry 4.0 now is imperative to staying competitive. "I don't think processors stand any chance of surviving if they don't embrace it," says Pepperl+Fuchs's Hornis. "Costs will go up, quality will go down and efficiency will plummet in comparison to their competitors who are likely employing Industry 4.0 technologies. It will be hard for a business to remain competitive when a large fraction of their market moves in that direction and they do not. There aren't too many typewriters around today and there's a reason for that." ■

Joy LePree

Focus on Weighing

Alfa Laval

This load cell is robust and hygienic

The UltraPure single-point load cell (photo) is a comprehensive solution for hygienic process weighing and measurement of liquid level, mix ratios, dosage or batching, and is suitable for weighing on small hoppers and vessels, scales or conveyor belts. With its patented technology, mounting kits are unnecessary and setup is quick and easy. A complete laser-welded construction makes the weighing system an ideal choice in processes where the production environment is hosed down on a daily basis. The pre-calibration of the load cells eliminates the need for onsite calibration in many applications. Mechanical protection devices are not necessary when installing these digital load cells. This is not only an important cost and maintenance saver, but also allows for a hygienic installation. Two standard accuracy ranges (0.05% and 0.025%) are available that cover a total measurement range up to 150 kg. — *Alfa Laval AB, Lund, Sweden*
www.alfalaval.com

Hardy Process Solutions

A new compact class for weighing technology

This company recently announced an upgrade to its weighing technology portfolio to include two complete packages for standalone applications: the new weighing terminals Siwarex WT231 for non-automatic scales and Siwarex WT241 for belt scales and solids flowmeters combine weighing electronics and a touch panel in a single unit. The two new weighing terminals can be set up as a standalone solution with the utmost speed and simplicity, and using an RS485 Modbus RTU interface, they also allow integration into any commonly used control environment. Due to its extensive diagnostic capability and limit value control, the Siwarex WT231 weighing terminal with integrated WP231 weighing module can be used in industries demanding a high degree of accuracy, like food and beverage production, and the pharmaceutical and chemical industries. The WT231 weighing terminal is suitable for measuring the amount of product in a bin or tank where the mass of the material is required. It can also be used where non-contacting measurement is needed, but other non-contacting technologies are not appropriate because of pressure or temperature. The Siwarex WT241 weighing terminal with integrated weighing module WP241 for belt scales offers not only a high level of measurement accuracy, but also an array of supplementary functions. — *Siemens Industry, Inc., Alpharetta, Ga.*
www.industry.usa.siemens.com

Adam Equipment

New CIP, open-source checkweighing machines

Introduced last September, the clean-in-place (CIP) version of the Dynamic Checkweigher is able to meet the demands of food or chemical manufacturers. The Dynamic Checkweigher CIP (photo) uses a framework that minimizes horizontal flat surfaces, using sloped faces and round tubing where possible, and a sloped cabinet. An enhanced safety conveyer design minimizes entrapment and other hazards from rotating shafts or equipment. The Dynamic Checkweigher Series is a fully automated system designed to automatically weigh items while in motion for quality control or sorting applications. — *Hardy Process Solutions, Inc., San Diego, Calif.*
www.hardysolutions.com

This weight indicator can be hosed down

The new AE 403 digital weight indicator (photo) features a stainless-steel housing that is IP67 rated, so the indicator can be hosed down or pressure-washed after use. This indicator performs well at food processing plants, in farm environments, on loading docks, or for shipping and receiving tasks. The AE 403 offers features and functions for numerous applications, including weighing, parts counting, percentage weighing and peak hold. A large backlit LCD has 40-mm-high digits that are easily viewed under any lighting conditions, reducing the chance of user error when recording results. Checkweighing is fast and easy, as

Note: For more information, circle the 3-digit number on p. 82, or use the website designation.

the display changes color when the weight is over, under or within limits. A capacity tracker on the display helps users easily monitor overloads. — *Adam Equipment, Oxford, Conn.*
www.adamequipment.com

Two new weight transmitters for automation applications

The ACT350 DIO and ACT350 Powercell Automation Weight Transmitters (photo) have been added to the ACT350 product family. Integration of analog and Powercell weighing systems into automation applications is now easier than ever. These new ACT transmitters provide enhanced network functionality and onboard I/O for direct local control of connected scales, load cells and weigh modules in conjunction with PLC application control. The ACT350 DIO Weight Transmitter delivers precision measurement at an exceptional speed (800 Hz PLC update rate) that is suitable for fast filling and sorting applications. The device supports fast PLC connectivity via add-on profiles and device description files, enabling complete weight integration in minutes. The ACT350 Powercell weight transmitter delivers precise measurement and monitoring of individual load cells. This device also supports fast PLC connectivity via add-on profiles and device description files. — *Mettler Toledo, Inc., Columbus, Ohio*
www.mt.com

Direct weighing technology with a very high capacity

The latest generation of this company's SensiQ WB weighbeam technology (photo) is said to be the world's highest capacity loadcell, with a nominal capacity of 600 metric tons (m.t.), and can be installed by simply bolting into the given steel structure. This makes it suitable for hopper scales with a total weight of up to 2,500 m.t., as well as for hoppers in train loading systems. The latest SensiQ WB development has an expanded operating temperature range between –40 and 180°C, an improved accuracy of 0.07% across the entire load range, and meets IP68 requirements according to ANSI/IEC 60529. The weighbeams connect directly inside the given structure without moving parts and transmit all disturbance forces and moments with minimal measuring-value interference. — *Schenck Process GmbH, Darmstadt, Germany*
www.schenckprocess.com

A checkweigher that also sorts tablets

The MG2 Selekta (photo) is a high-speed checkweigher and sorting machine for the production of tablets. Depending on the product, Selekta can check up to 500,000 units per hour, faster than anything else currently on the market, says the company. This technology is designed for seamless integration with existing tabletting equipment that allows for continuous process manufacturing. The Selekta incorporates the main benefits of the company's Multi-NETT weight control system. Multi-NETT affords the ability to monitor and control net weight in low-dose applications (5–25 mg). The system also can singularly monitor and control the net weight of multiple components dosed into a capsule, and rejects any capsule that exceeds preset weight tolerances. — *MG America, Inc., Fairfield, N.J.*
www.mgamerica.com

Affordably replace manual ingredient batching

The Affordable Batching Controller (photo) is a semi-automatic batching system that still requires operator involvement through each step in the batching process, but provides automated operator instructions and prompting, ingredient validation and lot tracking, automatic weighing with over/under tolerance control and more. This controller will eliminate bad batches that result from operator error and interruption. The operator no longer needs to keep track of where he or she is in the batching process — the automated Hand Prompt Batching Station does that automatically. The controller's PC and touchscreen display will ask the operator to weigh ingredients, then the controller sequences an operator through a formula one ingredient at time. The primary advantage of the system is to ensure that each ingredient is added to the container, is within a programmed weight tolerance and from the correct ingredient lot before the controller will index to the next ingredient to be added. — *Sterling Systems & Controls, Inc., Sterling, Ill.*
www.sterlingcontrols.com ■

Gerald Ondrey

Mettler Toledo

Schenck Process

MG America

Sterling Systems & Controls

New Products

Festo

Energy-conservation module improves pneumatic processes

Showcased last month at Interphex in New York City, this company's MSE6-E2M pneumatic energy-efficiency module (photo) monitors the condition of pneumatics on process equipment, skids or packaging machinery, enabling users to decrease consumption of energy and compressed air. The module provides automatic detection and notification of leaks, as well as condition monitoring for relevant process data. When paired with the new CPX IOT gateway, the E2M module provides realtime analytics with a direct connection to this company's cloud service. — *Festo Corp., Islandia, N.Y.*
www.festo.us

Tekleen Automatic Filters

New automatic filters integrate two stages into a single vessel

The CSF-ABW two-stage backwash filter (photo) is a fully automatic water-filtration system that is contained within a single vessel. The first stage is a coarse-screen flushing filter with a 1/8–1/2-in. slotted screen for quick self-cleaning. The second stage is a finer filter with screening capabilities down to 75 µm. These new automated filters offer direct filtration of a dirty water source, such as river water, lake water, industrial wastewater, dirty cooling water and many more. For simpler operation and maintenance, there are few moving parts inside CSF-ABW filters. — *Tekleen Automatic Filters Inc., Los Angeles, Calif.*
www.tekleen.com

Camfil APC

This dust collector has two cartridges and higher capacity

The Quad Pulse Package 2 (QPP2) dust collector (photo) has two main filter cartridges designed to handle air volumes from 590 to 1,765 ft^3/min. The QPP2 also features a cleanable filter system that allows manufacturers to run continuous production processes and avoid frequent filter replacements. The QPP2 cleans filters in four segments, one at a time, without interrupting airflow. The primary filters provide high filtration efficiency and remove the majority of collected dust. This design prolongs the service life of the second-stage HEPA filter, which provides 99.995% filtration efficiency to capture the finest, most hazardous dust particles. The HEPA filter is also a tested flame and contamination barrier. The QPP2 provides explosion protection in accordance with NFPA and ATEX standards. The pressure-shock-resistant housing maintains its integrity with no damage during an explosion event. The QPP2 can safely contain an explosion event without the need for additional safety devices, and it can be safely installed indoors close to processing areas. — *Camfil APC, Jonesboro, Ark.*
www.camfilapc.com

CP Pumpen

Pump hazardous media at flowrates up to 1,200 m^3/h

This company has launched a new pump size in its established MKP product range. With this new pump size, it is now possible to transfer hazardous media at higher flowrates using the efficient, rugged and safe magnetic drive pumps. The MKP 300-250-315 sealless magnetic drive pump (photo) provides flowrates up to 1,200 m^3/h with differential heads of up to 50 m. These sealless pumps are suitable for hazardous and aggressive media since they are completely leak-free. — *CP Pumpen AG, Zofingen, Switzerland*
www.cp-pumps.com

A new non-contact radar gage for liquid-level measurement

The NCR-84 is an 80-GHz radar used for continuous, non-contact level measurement in demanding liquid conditions, including excessive steam, vapor, condensation or surface foam. The signal is focused in a very narrow beam angle, allowing for precise aiming to avoid obstructions in the tank, such as agitators, mixers, fittings or heating coils. The NCR-84 is also appropriate for use in tanks with turbulent product surfaces, viscous media and pastes. This sensor is offered in threaded, flange and hygienic versions, as well as a plastic antenna option for use in low pressure or temperature ranges. The threaded 1.5-in. version makes it easier to mount existing small process fittings without mounting modifications. An optional 3/4-in. fitting enables mounting in space-constrained areas. — *BinMaster, Lincoln, Neb.*
www.binmaster.com

This pressure switch has an adjustable switch differential

The model PSM-700 rugged pressure switch (photo) offers a switch differential adjustable over a wide range, very high repeatability. The PSM-700 has a UL-listed micro switch that switches at electrical powers up to 250 V a.c. and 10 A. With a switch point repeatability of ≤0.5%, it offers long-lasting high reliability, says the company. The high adjustability of the switch differential — up to 60% of the setting range — enables flexible on/off switching. The instrument can be delivered with setting ranges from 1–1.5 to 7–35 bars. A robust aluminum case and wetted parts made of corrosion-resistant 316L stainless steel also enable the new pressure switch to be used under harsh conditions. A dual-entry option is possible for the electrical connection (top and side), which means that the instrument can be mounted in the optimal orientation. — *WIKA Alexander Wiegand SE & Co. KG, Klingenberg, Germany*

WIKA Alexander Wiegand

www.wika.de

Dry bulk solids with this fluidized-bed system

The HDC fluidized bed dryer (photo) operates in open systems, as well as in closed, inert-gas loops to keep dried granules in evenly floating, fluidized motion. Besides standard setups for such high-capacity applications as soda, polymer and fertilizer drying, for example, the technology range is also suitable for sophisticated applications requiring higher safety or efficiency standards. These fluidized bed systems are able to handle inflammable, combustible and dust-explosive products, as well as materials with critical flowability, high moisture content or even liquid feed materials. — *Andritz Group, Graz, Austria*

Andritz Group

www.andritz.com

Hybrid gas analyzer for emissions monitoring

The new Rosemount CT4400 continuous gas analyzer (photo) is said to be the world's first purpose-built quantum cascade laser (QCL) and tunable diode laser (TDL) analyzer designed to help plants reduce ownership costs and report emissions accurately in environmental monitoring applications measuring standard components, such as nitric oxide, nitrogen dioxide, sulfur dioxide, carbon monoxide, carbon dioxide and oxygen. Optimized for cold and dry applications running at ambient pressure, the CT4400 analyzer offers the benefits of QCL/TDL technology, including high sensitivity, accuracy, improved stability and low-

Emerson

For details visit adlinks.chemengonline.com/73854-39

Hans Turck

drift performance in a configuration that allows fast, easy integration into existing plant infrastructure. Because the system can hold up to four laser modules, it can measure up to seven application-specific gas components simultaneously, providing flexibility in continuous emissions monitoring systems (CEMS) applications. — *Emerson, St. Louis, Mo.*
www.emerson.com

Risk analytics enhance this cybersecurity platform

The newest release of this company's Cyber Integrity platform, Version 6.3, includes risk analytics to continuously measure and identify cybersecurity risks to multi-vendor OT (operational technology) endpoints, as well as forensic analysis capabilities that provide deep insight into the impact and propagation of a cyber-attack, including consideration of vulnerabilities, patch currency gaps, configuration baseline deviations and unauthorized configuration changes down to the field-instrument level. Cyber Integrity's risk-analysis functionality can also identify OT endpoint security degradation and risk propagation so that OT security specialists, automation engineers and risk/compliance managers can prioritize remediation. The forensic investigations are enabled by extensive multi-vendor configuration and referential insight to provide foundational control-system cybersecurity, enterprise scalability and platform independence. — *PAS Global, LLC, Houston*
www.pas.com

Dynamic Water Technologies

Pressure sensors with capacitive touchpads

The new pressure sensors of the PS+ Series (photo) can be commissioned particularly easily and provide reliable measurements with intuitive operation. Overhead mounting is possible, since sensor heads can be rotated over a range of 340 deg. After the sensor is connected, it automatically registers whether the controller or the bus module requires a current or voltage signal. A compatibility mode is also provided for the integration in IO-Link systems. The operator interface with capacitive touchpads and a color display enables settings to be carried out quickly in plain text, and is protected by a lock mechanism from accidental operation. The hermetically sealed keypad ensures greater resistance to dirt and liquids, so that the sensors meet the requirements of ISO protection to IP6K7K, IP6K7 and IP6K9K standards. The PS+ Series is designed for pressure ranges up to 600 bars and is available with ceramic measuring cells (PS310) or metal measuring cells (PS510). — *Hans Turck GmbH & Co. KG, Mülheim an der Ruhr, Germany*
www.turck.com

Kaman Precision Products

Electrochemical treatment saves water, reduces costs

The Universal Environmental Technology (UET) reactor (photo) is an electrochemical treatment system that balances process water, allowing it to be reused for multiple cycles. The technology offers multiple benefits, including water conservation, cost reductions, elimination of nearly all chemicals during treatment, maintenance savings, energy savings, increased equipment life and reduced downtime. One of the largest areas of savings is on blowdown — water that is discharged from cooling towers because of mineral buildup. The system increases the number of cycles that water can be used from about three in traditional chemical treatment to more than double that with the UET system. This also dramatically reduces the amount of makeup water needed to replenish the systems, says the company. — *Dynamic Water Technologies, LLC, Scottsdale, Ariz.*
www.dynamicwater.com

A family of displacement sensors for extreme conditions

This company recently launched the Extreme Environment product family of high-precision displacement sensors and associated systems (photo). Three separate systems are available, specifically designed for high-pressure, low-temperature and high-temperature conditions. The Extreme Environment sensors and systems work in operating temperatures ranging from –320 to 1,000°F (over 1,200°F short term). Displacement systems can withstand pressures up to 5,000 psi. Their dual-coil

sensor design effectively minimizes temperature effects. All high-temperature transducers are made with hermetically sealed, all laser-welded Inconel housings and use an Inconel-jacketed, mineral-insulated cable. The sensors are unaffected by environmental contaminants and can withstand corrosive gas or liquid environments, says the manufacturer. — *Kaman Precision Products, Inc., Middletown, Conn.*
www.kamansensors.com

Liquid-filled pressure gages that can withstand harsh chemicals

Model 1550 and 1553 pressure gages from this company's U.S. Gauge range (photo) are liquid-filled, which protects the internals from vibrations and pulsations encountered when the gages are mounted on pumps or compressors. Furthermore, liquid filling makes the gage easier to read because it dampens the pointer action and provides lubrication, extending device lifetime. The gages are available in 2.5- or

Ametek STC

4-in. sizes, with a pressure range from 0 to 15,000 psi. Vacuum-only and compound gages (up to 300 psi) are also available. All wetted parts are 316 stainless steel, enabling use with harsh chemicals, and the gage case is made from 304 stainless steel and features a crimped-on window, as well as a liquid fill plug at the top of the gage for easy filling. — *Ametek Sensors, Test & Calibration (STC), Berwyn, Pa.*
www.ametektest.com

Magnetic mixers for biotech and pharma applications

This company is expanding its range of magnetic mixers with the new LeviMag UltraPure (photo), which is engineered for the sterile production of biotechnological and pharmaceutical products. These mixers are based on the same patented, hygienic design as their predecessors, and feature an impeller


Alfa Laval

that levitates on a powerful magnetic field at all times, so there is no direct contact between the axial part of the bearing surfaces. They are designed to meet the demands of liquid-based pharmaceutical formulations that require the validation of mixer cleanability, drainability, bioburden control, low-shear performance and thorough documentation. Capable of operating at a broad range of speeds, the magnetic mixer features a specially designed four-wing impeller that delivers high pumping efficiency. This safeguards product integrity, provides full drainability and ensures efficient mixing, since the mixer can be run dry. — *Alfa Laval AB, Lund, Sweden*
www.alfalaval.com

Mary Page Bailey and Gerald Ondrey

Low-Temperature Handling Considerations

Department Editor: Scott Jenkins

Processes involving extremely low temperatures present unique process design and safety challenges. This one-page reference outlines considerations for low-temperature operations.

Direct contact

Extremely low temperatures can rapidly freeze human tissue. Contact between a worker's bare skin and a low-temperature vapor, liquid or solid can result in cryogenic burns. Contact is most likely when objects are being moved into or out of a low-temperature zone, such as a liquid-nitrogen-storage bath, during maintenance activities, or when low-temperature fluids are being transferred. If cryogenic fluids are involved, workers should wear long sleeves, long pants, thermally insulating gloves, and face and eye protection (a full face shield over safety glasses is advisable). Pants should not have cuffs, and gloves should be loose so they can be quickly removed. Even when low-temperature liquids are not handled directly, it is important to identify uninsulated pipes or vessels that contain them. If unprotected skin comes into contact with these surfaces, the skin may stick to them.

Embrittlement

Many materials embrittle at cold temperatures. This can be useful for size reduction of materials that would otherwise be too soft, oily or volatile to grind. However, many materials commonly used for ambient temperature systems, such as carbon steel or galvanized steel, lose their ductility as their temperature is lowered. This can result in a catastrophic failure of equipment or piping made from these materials if subjected to excessive stress at low-temperatures. Piping and pressure vessel design and fabrication codes, such as ASME B31.3 (Process Piping) and B31.5 (Refrigeration Piping and Heat Transfer Components), address this hazard by specifying minimum temperatures for materials of construction, plus materials testing and design restrictions for selecting and using materials at low temperatures. Materials that remain ductile at low temperatures include austenitic stainless steel (including types 304, 316 and 321), copper, red brass and many copper alloys and aluminum.

Thermal contraction

Most materials of construction will shrink as their temperatures decrease. For example, a stainless steel or copper pipe that is 100 ft. (30 m) long will contract linearly by about 3.5 in. (90 mm) as it cools down from 70°F to –320°F (20°C to –195°C). This thermal contraction is independent of the diameter of the pipe. The stresses generated by thermal contraction are large and will severely damage an improperly designed pipeline or piece of equipment.

Vapor expansion

Liquid nitrogen (Figure 1) expands to over 700 times its liquid volume when warmed to 68°F (20°C). This expansion property is used commercially to purge, inert and pressurize containers housing foods, drugs and chemicals that are sensitive to air or moisture by dropping a small amount of liquid nitrogen into the container during packaging. Low-temperature systems may need to be designed to accommodate the pressures that can be generated whenever a liquid refrigerant is trapped in a closed volume. For example, liquid nitrogen or liquid trifluoromethane can become trapped in a pipeline between two closed valves. As the cold liquid warms, the increase in vapor pressure can spring flanged joints and burst pipes. In liquid-nitrogen piping systems, this expansion is usually managed by installing a pressure relief valve, in pipe segments that can trap liquid. All thermal relief valves in a liquid nitrogen system should discharge to a safe location, ideally outdoors. In mechanical systems, the higher unit cost and other properties of the refrigerants used, such as trifluoromethane, means that thermal relief valves are not feasible. Instead, these systems typically incorporate expansion vessels.

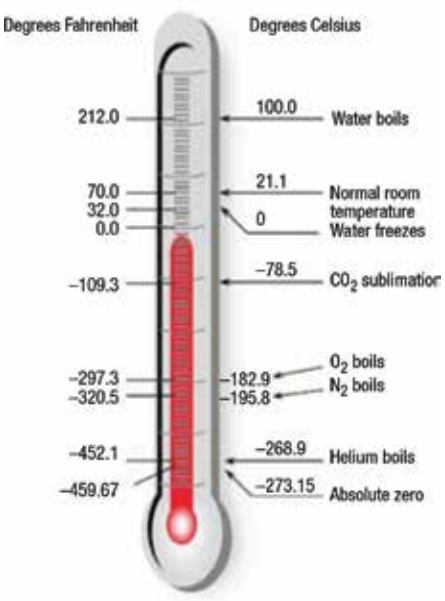

FIGURE 1. This temperature scale from 212°F to absolute zero shows the boiling points of nitrogen, oxygen and helium

Condensing nearby materials

The ability of cryogenic temperatures to liquefy substances with low boiling points is useful in many process operations. For instance, cryogenic temperatures can condense volatile compounds that cannot be separated from exhaust-air streams at ordinary refrigeration temperatures. The condensed material can often be reused and recycled instead of incinerated. If cryogenic liquids contained in vessels or piping are colder than the oxygen dewpoint of the surrounding air, an oxygen-enriched liquefied-air condensate will form on uninsulated surfaces. This can drip onto surrounding equipment and personnel, causing cryogenic burns. As the condensate warms and re-evaporates, the resulting local raised oxygen levels can create a serious fire hazard. In the case of H_2 and He, the surrounding air can even be solidified. This frozen air can block the discharge ports of pressure relief valves, preventing them from operating correctly. ■

Editor's note: This column was adapted from content initially published as part of the following articles: Easterbrook, N., Boland, T., and Farese, D. Extremely Low-Temperature Systems, *Chem. Eng.*, August 2015, pp. 38–44;. and Patten, T. and Dunphy, K. Flow Measurement in Bitter Cold: How to Use Coriolis Meters in Cryogenic Service, *Chem. Eng.*, July 2006, pp. 48–49.

Polyethylene Furanoate Production

By Intratec Solutions

Polyethylene furanoate (PEF) is a polymer synthesized from the copolymerization of 2,5-furandicarboxylic acid (FDCA) with monoethylene glycol (MEG). Since both monomers can be obtained from biomass starting material, and the resulting PEF is 100% recyclable, PEF is considered a bio-based analogue to polyethylene terephthalate (PET). Also, PEF production is thought to have the potential to reduce greenhouse gas emissions compared to the production of PET.

The process

Strong parallels are reported in the literature between the production of PET and PEF, to the point that existing PET assets may be used for PEF production. FDCA and MEG are polymerized in two steps (Figure 1) yielding bottle-grade PEF.

Melt-phase polymerization. MEG and FDCA are initially fed to the paste system, which prepares a uniform feed slurry batch-wise for melt-polymerization downstream. The mixture then passes through two agitated and jacketed reactors, in which esterification takes place, generating bis(2-hydroxyethyl)-2,5-furandicarboxylate (BHEF). Small amounts of water formed are removed, as well as the excess unreacted ethylene glycol that is boiled off and directed to the MEG recovery system.

BHEF is fed to an agitated, jacketed reactor. Here, vacuum and heat are applied for the removal of water and ethylene glycol, shifting the reaction equilibrium toward polymerization. Antimony glycolate is used as a catalyst. This pre-polymerization generates PEF oligomers. The ethylene glycol and water removed from the vessels by vacuum are directed to MEG recovery stage.

In the polycondensation step, the PEF oligomers undergo condensation reactions, increasing the degree of polymerization. The reaction occurs in a rotating-disc reactor under an even higher vacuum to remove water and excess MEG. Here, higher-molecular-weight PEF chains are generated, yielding a textile-fiber-grade PEF. Gaseous effluents from all reactors are condensed and fed to a distillation column, where MEG is recovered from the bottom and recirculated.

The previous melt-phase polymerization is concluded by a pelletizing step, in which the molten PEF is extruded, cooled and chopped into cylindrical shapes. The amorphous PEF chips are screened, classified, dried and then conveyed to a storage silo.

Solid-state polymerization. PEF chips are crystallized to prevent agglomeration due to high polymerization temperatures downstream. The particles are then polycondensed in the solid-state polymerization (SSP) reactor — a long cylindrical vessel.

The bottle-grade PEF chips are fed to a fluidized-bed cooler, which cools down the PEF and removes dust. The PEF chips are homogenized and packed in bags.

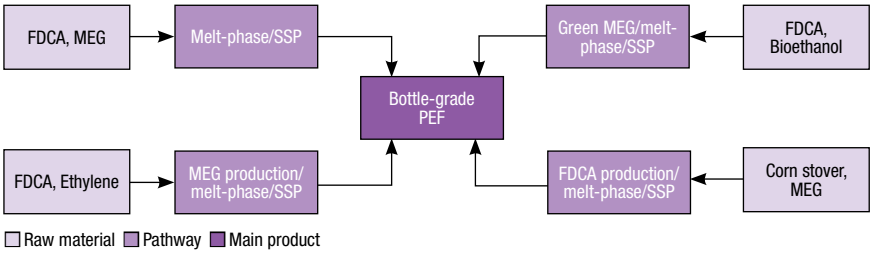

FIGURE 2. Different PEF production pathways are related to different sources of FDCA and MEG

Production pathways

Because PEF production consists of the copolymerization of FDCA with MEG, different PEF manufacturing routes are related to different sources of these materials (Figure 2).

Economic performance

The total operating cost (raw materials, utilities, fixed costs and depreciation costs) estimated to produce PEF was about $2,700/ton in Q2 2015. The analysis was based on a plant constructed in the U.S. with the capacity to produce 300,000 metric ton per year of PEF.

This column is based on "Polyethylene Furanoate Production — Cost Analysis," a report published by Intratec. It can be found at: www.intratec.us/analysis/polyethylene-furanoate-production-cost. ■

Edited by Scott Jenkins

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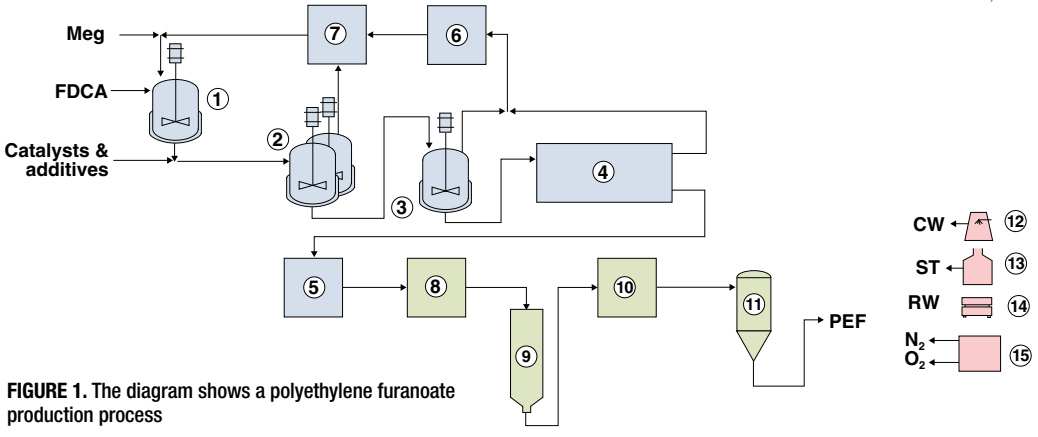

FIGURE 1. The diagram shows a polyethylene furanoate production process

1. Paste system
2. Esterification
3. Prepolymerization
4. Polycondensation
5. Pelletizing
6. Vacuum system
7. MEG recovery
8. Crystallization
9. SSP reactor
10. Cooler
11. Product silo
12. Cooling tower
13. Steam boiler
14. Chiller
15. Air separation unit

CW cooling water
ST steam
RW refrigerated water

Maintenance: Pursuing Improvements in Rotating Machinery

Part 1

The variety of rotating equipment used in chemical manufacturing creates the need for diverse maintenance methods. Using new techniques can greatly improve the reliability and performance of all types of rotating machines

Kirill Grebinnyk and Bob Krusemark
Sulzer

IN BRIEF

MANAGING POWER AND EFFICIENCY
OPTIMIZING ELECTRICAL PERFORMANCE
MINIMIZING RUNNING COSTS
UNDERSTANDING THE ISSUES
ANTI-FOULING PROTECTION
EXTENDING DURABILITY
POWER TRAIN MAINTENANCE
INSPECT AND TEST
COMPRESSOR REFURBISHMENT
TURBINE RENOVATION
STRESS CORROSION CRACKING
PERFECTING PUMP PERFORMANCE
BALANCING ISSUES
ADDITIVE MANUFACTURING
THE FINAL ANALYSIS

FIGURE 1. Electrical testing of new coils ensures optimum performance

The processes that are required to manufacture chemicals on an industrial scale rely on a large variety of rotating equipment to deliver the end product. From steam turbines and electric motors to compressors, expanders and pumps, every machine has a vital role to play. Keeping the manufacturing process running requires dedicated maintenance teams and expert knowledge to deliver reliability and performance.

Installed pieces of rotating equipment are operated for numerous years — decades in many cases — and at some point, will begin showing signs of age. In some cases, the original equipment manufacturer (OEM) may no longer support the older models or may even have ceased to exist. In other situations, the lead time for a major overhaul may not match the expectations of the plant owner. Whatever the case, modern design and manufacturing processes can be applied to time-served equipment and deliver cost-effective improvements.

Managing power and efficiency

From onsite generators to the numerous electric motors, reliable operation of electrical assets within a manufacturing plant in the chemical process industries (CPI) is vital. Unexpected failures can cause considerable inconvenience and lost production, which will impact revenue. So, once again, a preventative maintenance program can provide significant

benefits by reducing downtime and improving operational efficiency.

The use of vibration analysis, combined with thermal imaging, which is used to identify imminent bearing failure, poor electrical connections and the imbalance of phase loadings, can produce an accurate indication of the overall status of the equipment. Additional testing of the electrical winding, especially partial-discharge analysis above 6,000 V, can also provide very useful information on the overall condition of the equipment, as well as an indication of its remaining lifetime. For larger electrical assets, a repair will usually be more cost-effective than replacement, while still offering the opportunity to improve on the original design.

Continuous advancements are being made in insulation technology, and they have allowed the same insulating properties to be delivered by a thinner layer of material than in the past. Using thinner insulation, engineers must apply good design practices to keep voltage stresses to acceptable levels, which helps to extend the operating life of the motor. When the insulation is optimized, the percentage of copper in the winding can be increased, which, in turn, can reduce operating temperatures or improve output, as well as energy efficiency.

FIGURE 2. Experienced engineers are key to delivering effective repairs, and often these tasks require highly specialized equipment or facilities

Using the information gathered from the preventative maintenance routines, it is possible to plan repairs so that they coincide with planned shutdowns or outages. Working with independent repair specialists, new windings can be designed, manufactured and tested ahead of time, minimizing project duration and delivering longterm reliability.

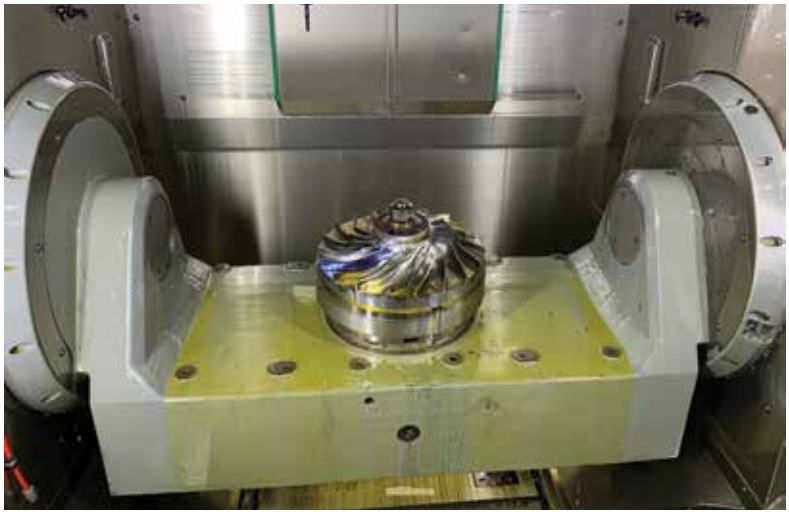

FIGURE 3. Five-axis milling is used for precision manufacturing of pumping impellers

Optimizing electrical performance

In the case of electrical assets, such as generators and motors, monitoring the condition of the stator and the insulation on the windings provides vital information about the future reliability of the machine. Electrical insulation degrades over time, and the speed of its deterioration is affected by the operating temperatures and stresses that it is subject to.

Situations of voltage imbalance, over- and under-voltage, voltage disturbance and operating temperature all play a role, so a proactive approach can offer considerable benefits. Optimizing supply characteristics can extend the service life of the equipment, while using advanced techniques, such as partial-discharge analysis on high-voltage machines, can provide vital information about the condition of the stator.

Since the breakdown of electrical-equipment insulation is a very gradual process, implementing a condition-monitoring program is an ideal method for optimizing asset performance. Data from resistance temperature detectors (RTDs), metering devices and partial-discharge couplers enable the operator of the machine to extend its service life to the optimal point where the windings need to be replaced. This "inside information" helps to avoid unexpected failures and allows the coil replacement to be scheduled along with other planned maintenance activities, minimizing disruption (Figure 1).

The refurbishment of stators and rotors as part of a planned maintenance scheme will provide a considerable extension to service life and, in many cases, it can also achieve improved efficiency. Enhanced design capabilities, production techniques and insulation technologies enable modern coils to have an increased copper content, compared to the original parts, which reduces heat buildup and improves energy efficiency.

Minimizing running costs

The operation of some equipment, such as pumps and compressors, demands considerable energy. It is commonly accepted that 95% of the annual running costs can be attributed to energy expenditure for these equipment classes. By improving the performance and efficiency of these machines, the running costs can also be reduced.

Rotating equipment that is in direct contact with the process media and under constant environmental attack presents a major challenge. It is possible, however, to reduce degradation to a minimum by selecting the correct protective coatings. Generally, turbines, compressors and pumps are all subject to a variety of environmental conditions that contribute to corrosion, erosion, fouling and various other process-related issues that will require maintenance intervention.

Many metals form oxide layers that adhere to and passivate the equipment surface to prevent further corrosion, but the change in the physical characteristics of the equipment surface significantly increases the frictional properties and thus decreases aerodynamic efficiencies. So, there is a balance to be struck between protection and efficiency, which is where advanced coatings can help.

Understanding the issues

The first step is to understand the operating environment of the machinery. From there, the sources of degradation can be classified, and specific coating systems can be used to increase efficiencies, lengthen the interval between scheduled maintenance and reduce unplanned outages.

In the harshest of operating conditions, solid or liquid particles can pass through the equipment, causing erosion. Erosion that results in moderate to severe material loss can change aerodynamic efficiencies significantly. If left unattended, erosion can even affect the strength of the critical components and lead to premature wear of a blade or vane, as well as failure in service.

In operating conditions where both erosion and corrosion are present, the latter can be the primary source of attack that initially weakens the substrate surface. This chemical reaction between the component surface and the fluid passing through the turboma-

chine's flow path removes any passivation and leads to an increased rate of erosion.

Anti-fouling protection

Fouling in turbines and compressors can be caused by the presence of small particles in the ingested air streams, process gases or steam. Fouling can cause an increase in the surface roughness of the critical flow-path components, leading to a reduction in efficiency. This is a particularly serious issue in processes where sticky hydrocarbon aerosols are constantly present.

In situations where these circumstances exist, and their effect needs to be minimized, specialized coatings can provide improved anti-fouling protection. These can be applied to both stationary and rotating blades, as well as diaphragms, guide vanes, rotors and impellers. The exact composition of these coatings can be tailored to specific applications and will include an aluminum base coat for corrosion protection, as well as an inorganic sealer and a specialized non-stick final layer.

FIGURE 4. High-quality, precision parts are required for refurbishment of pumps and compressors

Typically, anti-fouling coatings will have a thickness between 75 and 125 micrometers and incorporate polytetrafluoroethylene (PTFE), which gives excellent chemical resistance in low to medium temperatures with a maximum operating temperature of 550°F (290°C). PTFE provides excellent protection from

FIGURE 5. At-speed balancing facilities ensure smooth operation in service

chemical attack by substances with a pH between 3 and 9, as well as resistance to many solvents and fuels. In applications that require protection beyond these limits, more specialized coatings can be created to provide enhanced defense against fouling.

Extending durability

Specialized coatings can be metallic, ceramic or any combination of the two that may be required to meet a broad range of physical criteria. Aside from protecting against fouling or corrosion, they can also provide protection against wear, high temperatures or direct chemical attack, as well as providing a substitute for chromium, which can become hazardous under certain circumstances.

In each situation, expert assessment and diagnosis can lead to a prompt proposal for a solution that will significantly improve the durability of the affected components. In many of the scenarios described so far, the use of specialized coatings can deliver a considerable extension in service life, as well as a more energy-efficient application.

Legacy equipment can benefit from the application of modern coatings, since some of the older materials may not have adequate properties to withstand the modern-day operating conditions. Minimizing oxidation and corrosion rates is an important step in reducing downtime and expenses for maintenance and therefore improving productivity and the asset's return on investment.

This is most commonly achieved with coatings containing aluminides that are applied by a variety of thermal-spray or surface-deposition techniques. By using an aluminum base coat, corrosion-resistant coatings are designed to be conductive and provide cathodic protection against corrosion. The aluminum protects the less-active base metal, sacrificing itself by enabling electron flow from the aluminum to the base substrate, which becomes negatively polarized and therefore protected against corrosion.

Solid and liquid particle erosion or fretting wear can be minimized by using coatings that increase the hardness of the protected material surface. Stellite (cobalt-chromium alloy), chrome-carbide and tungsten carbide are examples of hard-face coatings. These exhibit hardness in the 50–60 HRC range on the Rockwell Scale, which is based on a material's indentation hardness.

Power train maintenance

Some processes within the CPI, such as ethylene production, are particularly demanding in terms of power, and will often have several dedicated processing lines that include steam or gas turbines driving large compressors. These pieces of equipment require regular inspections and periods of planned maintenance to keep them operating reliably and efficiently.

Equipment such as large compressors will often have spare rotors that can be quickly exchanged during a planned maintenance period to minimize any downtime. This allows the rotor that has been in service to be repaired, and if necessary, upgraded, before being returned to operation during the next planned outage.

Compressors are subjected to some major mechanical and thermal stresses, which can affect the reliability of the equipment, especially as it ages. However, modern materials and design techniques can be used to return components to their original specifications or implement significant improvements in terms of efficiency and reliability.

Inspect and test

The process of inspecting and repairing compressor rotors requires considerable expertise, as well as access to highly specialized facilities to complete any significant repairs (Figure 2). Using a range of non-destructive testing (NDT) procedures, such as wet-magnetic-particle inspection and liquid penetrant inspection, it is possible to identify any defects in the components and to propose the most effective method of repair.

From this point, basic components, such

as shaft-seal sleeves, split rings and stepped impeller keys, can be easily manufactured, but specialized tasks, such as improving the impeller geometry, will require greater expertise and advanced engineering. In addition to that, processes such as high-velocity oxygen fuel (HVOF) spray systems can be used to improve or restore a component's dimensions and save significant expense by reconditioning existing components instead of replacing them altogether.

In situations where a component has failed, it is still possible to reverse-engineer it to manufacture a new part — even the major rotating or stationary components, such as impellers, inlet guide vanes or diaphragms. Independent turbomachinery maintenance providers offer the proper skills and resources to save a damaged shaft down to the chemical composition and mechanical properties of its base material by weld-repairing it and machining to the dimensions of the original part.

Compressor refurbishment

Used extensively in the chemical industry, large-scale compressors perform a particularly challenging role that places considerable stress on the component parts. Regular maintenance inspections and planned repair schedules are essential for continued reliable operation, especially for the rotors.

Eventually, the time will come when, due to wear, an impeller cannot pass an NDT procedure or becomes damaged, and new parts will be required. In the past, the lead time on these components could be considerable, but today, using laser scanning, three-dimensional computer-aided design (3-D CAD) and other numerical simulations that predict the stresses and flow conditions to which the component is exposed, it is possible to create high-quality precision parts with minimal delays.

In fact, it is often possible to refine the impeller design together with changes to the vane geometry and deliver a more efficient gas-path design. Combined with improvements in materials and manufacturing technologies, it is possible to deliver considerable benefits to older compressors.

For example, modern impeller components can be manufactured from a solid piece of a low alloy or stainless steel using five-axis

milling (Figure 3) or electrical discharge machining (EDM). If required, a new operating curve can be produced to illustrate the improvements in performance and efficiency. This information can be used to highlight the cost-effectiveness of the project, as well as the return on investment.

Turbine renovation

Large-scale assets, such as compressors, require reliable and efficient power sources, often represented by steam turbines. However, these machines are also operating in quite challenging conditions and suffer from similar damage mechanisms to the ones described previously. Clearly, as with any vital asset, they need to be monitored by a series of vibration sensors as part of a preventative maintenance routine.

By building a longterm performance trend that includes all operational aspects of the turbine, it is possible to identify the most appropriate time to carry out planned repairs, optimizing time-in-service and avoiding unplanned outages. Again, this type of forward planning minimizes downtime by ensuring all the parts and resources required are available for an efficient and effective maintenance project.

Stress corrosion cracking

Older steam turbines are prone to stress corrosion cracking, which can be caused by a number of factors, and getting to the root cause can take considerable effort. However, investing the time in failure analysis pays off in the long run, as the performance and reliability of the turbine will be assured and the findings may also be useful for similar pieces of equipment.

Identifying the cause in each case requires considerable expertise in material science. In-depth examinations using scanning electron microscopes and other specialized equipment are often required to establish the root cause of any cracking. In some cases, the mechanical properties of the base material may have been out of specification, while in others, a combination of deteriorating mechanisms may create a situation that enables the progression of stress corrosion cracking.

When the time comes for turbine refurbishment, it is essential to engage expert engineers with the skills and equipment required to identify the best repair practices, manufacture new parts and rebalance the entire assembly. None of these tasks are simple and all must be completed to the highest standard in order to achieve a durable and robust repair.

Perfecting pump performance

Like a great deal of modern machinery, pumps are required to operate with minimal downtime and with extended maintenance intervals. Pumps in the CPI have to cope with a wide variety of media in many applications, which means that there can be numerous types and designs of pumps within one plant.

At the center of a pump's design is the impeller, which provides an increase in the fluid head. As a result, impellers are subjected to the most damage, which can have a huge impact on efficiency, productivity and running costs. Therefore, it is very important to be able to source new impellers when they are required and, if necessary, take advantage of the latest improvements in design and materials technology to increase reliability.

As discussed with compressor components, creating replacement parts has become a much quicker process than in years past, with reverse engineering being used to design and manufacture improved components (Figure 4). Improvements to the flow geometry combined with the latest manufacturing techniques, such as using five-axis milling or rapid prototyping techniques to print casting molds, can reduce the lead time required to procure the replacement parts and deliver significant improvements in performance and reliability.

Balancing issues

One of the most crucial stages of the repair process is the balancing of the rotating components. Rotors operate at high speeds and with small clearances in the bearings, as well as between the rotating and stationary parts, so precision balancing is essential for continued reliable operation.

Low-speed balancing is carried out as components are rebuilt, having been refurbished or remanufactured. For multicomponent rotors, such as those used in turbines and compressors, the rotor is balanced at each stage of reassembly, before finally passing a rigorous quality-

control inspection.

One of the last steps is to carry out an at-speed balance test, the parameters of which are normally agreed upon with the user beforehand. This requires a dedicated balancing bunker, equipped with specialized pedestals and frequently operated in a vacuum to reduce the run time and energy used during the test (Figure 5). Such specialized equipment is only operated by OEMs and experienced independent maintenance providers.

The at-speed balance test involves the entire rotor assembly running at maximum continuous operating speed (MCOS) and beyond, while being monitored for vibration through special bearing pedestals, which are equipped with accelerators or velometers and a set of proximity probes. A rotor has to be low-speed balanced, typically in the range from 500 to 800 rpm, before proceeding to balance it at the operating speed. The American Petroleum Institute (API), in its respective standards for turbomachines, including API 610, API 612, API 617, defines MCOS as 105% of the highest specified design speed of the rotor assembly, and that the trip speed should be 110% of the MCOS.

Throughout the high-speed balancing process, vibration levels are monitored, and state-of-the-art software can be used to determine the optimum size and position of any balance weights that need to be added. This procedure also relieves residual stresses introduced during the repair process and ensures continued smooth operation of the rotor while in service.

Additive manufacturing

Taking advantage of new technologies, such as additive manufacturing (also called 3-D printing), can deliver fast and cost-effective prototyping for design assessments, as well as one-off molds and cores for parts manufacturing. This enables pump components to be recreated with a geometry that exactly matches the application, which may have changed since the initial commissioning.

Combined with the use of specialist coatings, pump remanufacturing has the potential to deliver considerable improvements on legacy designs. Using modern materials and manufacturing techniques, it is possible to create assets that are much better suited to their applications, with improved efficiency and durability.

The final analysis

The logistics and planning for refurbishing any equipment should not be underestimated. From the field-service crews involved in the removal and re-installation, to parts remanufacturing and at-speed balancing, coordinating all of the resources for a single repair project takes considerable expertise.

By implementing and following a preventative maintenance program, it is possible to make significant improvements in performance, reliability and efficiency of critical plant equipment. At the same time, utilizing expert knowledge and state-of-the-art analysis techniques, it is possible to understand and address any equipment design issues or material deficiencies. ■

Edited by Mary Page Bailey

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Maintenance Strategies in the Era of IIoT

Part 2

The shift from reactive to prescriptive maintenance can be greatly aided by advanced digital tools and the implementation of an effective pilot program

Kim Custeau
AVEVA

IN BRIEF

SMARTER MAINTENANCE THROUGH ANALYTICS
ANALYTICS FOR LIFECYCLE MANAGEMENT
DIGITAL TWINS AS A MAINTENANCE STRATEGY
EMPOWERING THE WORKFORCE
GETTING STARTED
COMPREHENSIVE DIGITAL STRATEGIES

To be successful in today's industrial business environment, companies in the chemical process industries (CPI) must maximize profitability across both asset and operations lifecycles. That means continual focus on everything from how an asset is designed and engineered to how it is operated, maintained and kept running with optimal availability and uptime. At the same time, the enterprise must also optimize every second of its operations lifecycle to stay competitive.

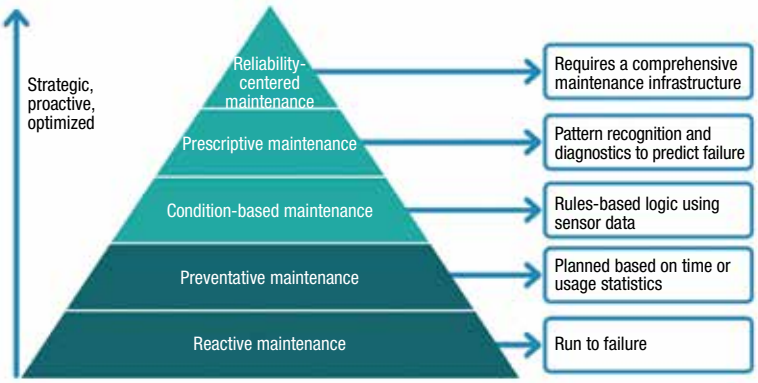

FIGURE 1. To optimize maintenance costs, engineers must carefully consider which assets truly require the investment for advanced programs, and which non-critical assets can simply "run to failure"

The industrial internet of things (IIoT) continues to enable smart equipment and increase access to data. While data collected by sensors have become priceless assets to the enterprise, the ability to make sense and use them to drive new insight is where the real value lies. To improve asset performance and reliability, CPI companies are leveraging the combination of data and many different types of predictive and prescriptive maintenance strategies.

Smarter maintenance through analytics

Strategic maintenance programs provide numerous benefits to the enterprise: assets can be kept running reliably with fewer failures, less downtime and related costs, and they are safer to operate — reliable uptime means that productivity is more predictable and profitable.

Outside of that, a comprehensive maintenance program makes valuable information accessible and provides context for smarter decisions. It requires a broad portfolio to collect data on assets, analyze it, determine the next course of action and use that action to further refine and optimize processes. This continuous improvement program is outlined in the maintenance maturity pyramid (Figure 1).

The higher you move up the maintenance maturity pyramid, the more proactive the strategy becomes and the more advanced warning of equipment problems is required. This enables maintenance teams to better plan resources, order materials and minimize unplanned events.

A complete maintenance program includes several approaches that are appropriate for the many different types of equipment used in CPI plants, with the goal of obtaining the greatest return on each asset.

- With reactive maintenance, the asset runs until failure. This approach is designed for non-critical assets that have little to no immediate impact on safety and have minimal repair or replacement costs. These types of equipment do not usually warrant an investment in advanced technology.
- In contrast, preventative maintenance (PM) strategies are intended to prevent asset failure. PM strategies suggest maintenance work to be conducted on a fixed schedule or based on operational statistics and manufacturer or industry recommendations. Preventive maintenance can be managed in an enterprise asset management (EAM) or computerized maintenance management system (CMMS).

- Condition-based maintenance (CBM) focuses on the physical condition of equipment and how it is operating. CBM is ideal when measurable parameters are good indicators of impending problems. The condition is typically defined using rule-based logic, where the rule does not change depending on loading, ambient or operational conditions.
- Predictive maintenance (PdM) relies on the continuous monitoring of asset performance through sensor data and prediction engines to provide advanced warning of equipment problems and failures. It typically uses advanced pattern recognition, machine learning or artificial intelligence (AI) and requires a predictive analytics solution for realtime insights into equipment health. For more information on AI, read "Artificial Intelligence: A New Reality for Chemical Engineers," *Chem. Eng.*, Feb. 2019, p. 14–17.
- Risk-based maintenance is a comprehensive prognostic strategy that balances the risk of asset failure with the cost to maintain assets, allowing plant operations and maintenance personnel to make decisions that support overall business objectives. As a result, the planning for maintenance and the operation of equipment exceeds safety and reliability goals while also maximizing return on asset investment.

FIGURE 2. A comprehensive digital twin of an entire plant can be the ultimate maintenance strategy, in that it integrates process models and simulation with continually updated sensor data to give a full picture of operational status

For more complex and critical assets, a prescriptive strategy is generally the best approach. Prescriptive analytics enables personnel to detect and address subtle variations in equipment behavior before they become problems that significantly impact operations. Unscheduled downtime can be reduced because personnel receive early warning notifications of developing issues. Maintenance costs can be reduced due to better planning, and parts can be ordered and shipped in advance to avoid delays, which means equipment can continue running. Additionally, some suggested maintenance win-

FIGURE 3. Virtual-reality (VR) training simulators can streamline the knowledge transfer between new and experienced operators

dows can be lengthened as determined by equipment condition.

Prescriptive analytics in support of a PdM strategy are also helpful in identifying issues that may not have been found otherwise. According to a study of common failure patterns by ARC Advisory Group (Dedham, Mass.; www.arcweb.com), only 18% of asset failures had a pattern that increased with use or age [*1*]. This means that traditional maintenance alone is not enough to avoid the other 82% of random asset failures — a more advanced approach is clearly required. Prescriptive analytics software can use historical operational signatures for each asset and compare it to realtime operating data to detect subtle changes in equipment behavior. These software tools can identify changes in system behavior well before traditional operational alarms, creating more time for analysis and corrective action.

With prescriptive maintenance, personnel know where inefficiencies are and can detect and react accordingly. A prescriptive maintenance strategy allows workers to understand why issues occur and use this information to understand the impact of performance deficiencies on current and future operations. This information also helps users assess the risk and potential consequences associated with each monitored asset, and can also be used to better prioritize profitability and operational expenditures. As a result, the planning for maintenance and the operation of equipment is safer and more reliable.

Analytics for lifecycle management

Prescriptive analytics are also very useful for "what-if" scenarios. By combining realtime and historical data, operators can assess potential outcomes of operational states and behaviors based on multiple variables. Deterministic or non-deterministic models can then be applied for open-loop simulation and prescriptive analytics. For example: Given the turbine's current maintenance state, how long can it run before failure and how likely is it to fail?

To make this analysis possible, data must be captured and turned into actionable insight through four key processes:

1. Connect people, processes and assets using digital technology and tools that increase operational safety, efficiency and agility
2. Collect and contextualize the data your enterprise generates to increase situational awareness across key performance and scorecard indicators
3. Analyze information with machine learning and advanced pattern recognition to drive predictive insights on process and operations that identify value leaks in the enterprise and expose new market opportunities
4. Act to reduce downtime, optimize asset management and maintenance, increase overall equipment effectiveness and drive new user experiences

The four steps above enable the creation of digital twins of enterprise operations and asset lifecycles. Using digital twins enables advanced modeling of everything from individual asset performance to full-scale plant and facility production optimization.

Digital twins as a maintenance strategy

A digital twin is a digital representation of a physical asset, like a pump, motor, turbine or even an entire industrial plant (Figure 2). The digital twin allows operators to predict asset behaviors based on simulation of the asset in various conditions. To effectively enable asset lifecycle management, the twin requires complete and continuous data input from asset design through operations.

The process starts with unified engineering in which process design, modeling and simulation are combined with overall plant design to create an integrated engineering environment and collaboration workflow. This results in significant reduction of engineering effort, easier collaboration among stakeholders and a lower total cost of engineering.

In the design phase, the use of digital models allows analysis of processes, equipment and operations through multiple simulations for optimum safety, reliability and profitability. As the physical asset's operational life continues, a digital clone of the asset can be updated in real time.

Creating digital twins of assets allows users to optimize asset performance, reliability and maintenance. Throughout asset deployment and commissioning, the digital twin is continually updated with ongoing operational and process data, such as maintenance and performance

records. The digital model uses predictive learning technology to proactively identify potential asset failures before they occur.

With the availability of low-cost sensing technology, sensor networks become another data point in generating an asset's digital twin, particularly for legacy assets that were not born digital. As digital tools, such as predictive analytics and machine learning software, monitor the physical asset and its environment through sensor networks and other data sources, a variety of cloud-based or on-premise tools can be applied to predict equipment failures before they occur while maintenance is scheduled around optimum economic and production conditions.

Most assets designed and deployed today have digital communication and connectivity built in. For assets and facilities commissioned before widespread digital connectivity, digital workforce enablement combined with mobile operator rounds and sensor technology provide a path toward creating digital twins of legacy assets while offering substantial improvement in workflow efficiency and accelerated operator training through augmented and virtual reality (AR/VR) technologies.

Empowering the workforce

Beyond maintaining physical asset reliability, maintenance strategies and solutions have broad impact across an entire enterprise. As industrial organizations manage transitioning workforces, predictive analytics solutions can help ensure maintenance decisions and processes are captured and repeatable by incoming personnel.

Other digital technologies augmented by data analytics facilitate improved knowledge transfer and increased situational awareness throughout the enterprise. For example, operator training simulators (OTS) powered by AR/VR technology bring to life digital twins of assets, control rooms and entire plants in a safe and controlled learning environment. Immersive technologies, such as head-mounted VR (Figure 3) displays and 3-D projection, allow real-world training simulation in the digital control room or plant.

Similarly, mobile technology enables workers to collect data from non-instru-

mented and stranded assets, enhancing operational visibility and increasing situational awareness across all maintenance and reliability functions. Mobile operator rounds digitalize operational processes, ensuring best practices are followed by operators at all times while enabling realtime team collaboration during problem resolution. From the mobile operator, tasked with keeping systems running now, to the reliability engineer focused on ensuring systems will run tomorrow, mobile technology is a driving force behind digital transformation.

When these technologies are coupled with digital twin technology, operators and plant personnel can begin to visualize processes and assets in real time, accelerating new insights on enterprise operations and improving knowledge transfer between new and experienced operators.

Getting started

Many CPI companies are beginning their digital transformation journeys by piloting predictive maintenance solutions, which can provide an immediate and measurable return.

As part of a digital transformation journey, pilot projects of digital solutions, such as predictive analytics and maintenance, can help the enterprise understand the best technology investments to improve profitability and maximize return on capital.

To ensure an organization is able to thoroughly evaluate new technology and gain value from the pilot project, consider the following guidelines.

Recruit leadership support. With any technology project, it is important to get buy-in from the executive leadership team. Some leading companies have even developed specific teams focused on digital transformation to ensure broad support.

Define scope and success at the start. To ensure success, you first need to define what that looks like. A good partner will work with you to identify specific and measurable outcomes that will result from implementing the technology. The focus of the pilot should not be to define a business case, but to instead prove a business case. For example, proving that the software can predict equipment failures to avoid significant repair costs.

Create a timeline. It is critical that a timeline is attached to the pilot program that specifically defines a deadline to officially adopt the technology. If the technology's value cannot be proven within that timeline, it may be best to move on to alternate solutions.

Conduct formal project management. Pilot programs require the same level of attention and discipline as a production-level implementation. Assign resources, and put a documented project plan in place before the pilot begins.

Put people first. No matter how great a new technology works, if people cannot use it, it is not worth the investment. That means putting a training program in place, and if the pilot is successful, continuing to invest in training on a regular basis.

For those organizations not equipped to handle the monitoring process internally, predictive maintenance can even be outsourced and performed in-house or offsite. Monitoring and diagnostics providers can put forward a team to manage the entire maintenance process, or to supplement internal activities through model training, diagnostics and best practices.

Regardless how an organization staffs this type of project, these services empower companies to leverage predictive maintenance, while reducing total cost of ownership.

Comprehensive digital strategies

Many benefits are realized when considering the maintenance costs that "could have been," including replacement equipment, lost productivity, additional personnel hours and so on, when a major failure is avoided. A complete maintenance strategy combines enterprise data capture with asset management, prescriptive analytics and risk-based management. Work orders can be automatically generated to relieve maintenance issues. Analytics capabilities continue to evolve from predictive to prescriptive — from what will happen to what should be done. ■

Edited by Mary Page Bailey

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Part 3

Modern Instrumentation Simplifies Maintenance

Built-in diagnostics and condition monitoring improve maintenance, process reliability and plant availability

Howard Siew
Endress+Hauser

IN BRIEF

SMART INSTRUMENTS

CALIBRATION AND VERIFICATION

SUPPORTING SOFTWARE

Today's modern world is steadily digitizing all our daily routines, but the majority of the chemical and petroleum-refining industries remains far behind current technology. The maintenance process is especially lagging due to old operating systems, lack of exposure to new technology and conventional mindsets regarding maintenance of instrumentation.

A typical maintenance strategy in a chemical plant involves performing planned routine maintenance and only being reactive once equipment fails to the point of introducing reliability or safety concerns. Then the maintenance crew rushes to replace the device if it's available as a spare or expedites shipment from the manufacturer. Meanwhile, the process is shut down.

Even though instrumentation nowadays is getting "smarter," with functions such as self-diagnostics and condition monitoring (Figure 1), most plants don't take advantage of it. Unfortunately, 97% of the smart instrument data are not being used.

This article discusses how modern instrumentation and supporting software can replace the conventional planned and reactive maintenance strategies that consume too much time and cost too much money in terms of labor and unnecessary calibrations. Modern instrumentation also greatly improves reliability and availability of the facility by diagnosing and predicting device failures before a process must be shut down.

With diagnostic information readily available, maintenance personnel know the exact health conditions of all devices. This enables them to perform the right maintenance at the optimal time, avoiding over-maintaining equipment that doesn't need it.

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FIGURE 1. Modern instruments, such as this Coriolis flow meter, have built-in diagnostics and condition monitoring

Smart instruments

NAMUR NE 107 (Figure 2) is a standard that every instrument manufacturer follows when devices are being designed and manufactured. It provides diagnostic codes with clear messages and remedies, including maintenance required, function check, out of specification and failure. With this information, the maintenance crews obtain clear direction on how to troubleshoot and fix the issue before the device deteriorates to complete failure.

A green diagnostic code indicates a healthy instrument. Orange means the instrument is undergoing a functional check, so the signal is invalid. Blue signifies that the instrument signal is valid, but maintenance is required soon. Yellow identifies that conditions may have caused an out-of-specification situation and therefore an uncertain signal. Finally, red represents a failed instru-

ment providing an invalid signal and requiring immediate maintenance.

The NAMUR 107 data are sent over fieldbus, EtherNet/IP, 4–20 mA HART, Wireless HART or other connection methods as an alarm message (when conditions apply) or when interrogated by a control system.

Modern instruments can easily provide these data because almost all instruments from major vendors employ self-diagnostics. Self-diagnostics means that the instrument is capable of detecting when it has a problem by continuous monitoring of relevant internal parameters related to its mechanical, electromechanical and electronic components.

Typically, during the instrument's design phase, a failure-mode-effects and diagnostic analysis is performed to identify critical components in the signal chain, starting at the process-wetted parts and followed by the electro-mechanical components, amplifier board, main electronic module and outputs. A proper margin of safety is then assigned to every critical path or component.

Firmware in the transmitter continuously monitors the entire signal chain for deviations. For example, if the diagnostics detect an error, it sends an event message conforming to NAMUR 107. The event is displayed on the instrument's front panel and is available to the automation system. Some instruments also send troubleshooting tips and remedial instructions.

Calibration and verification

Depending on the industry, instruments must be calibrated periodically. For example, the chemical industry has requirements for proof testing per IEC 61508 and IEC 61511.

Under old maintenance practices, where calibration is scheduled every six months or so, processes are shut down while the flowmeter or pressure transmitter is bypassed or removed from the line, possibly taken to a laboratory, calibrated, and then either reinstalled or put into spares.

In some cases, instruments are found to be far out of calibration, and have been giving erroneous readings. The problem is, how long has it been out of calibration and how many out-of-specification products were produced? The plant has no way of knowing.

On the other hand, many instruments are found to be perfectly calibrated, so the entire calibration process was a waste of time and money. Self-verification avoids this unproductive effort.

A self-verification is initiated on command from the automation system or at the instrument itself (Figure 3). During self-verification, diagnostic routines perform checks and generate a report which can be used to verify the device is still working properly.

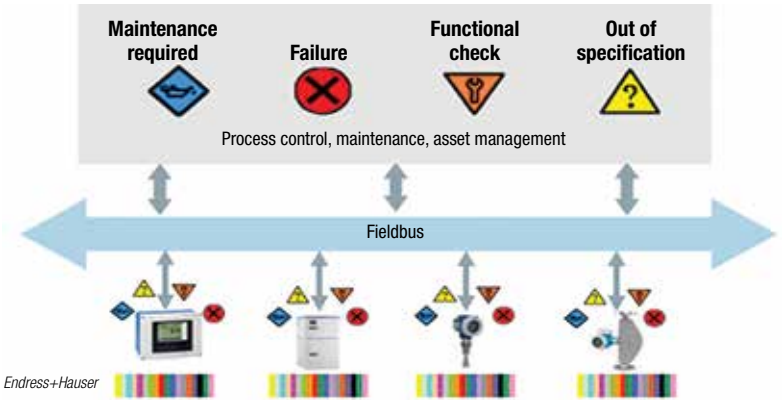

FIGURE 2. Almost every instrument manufactured today provides NAMUR 107 data

For example, commercial systems are available that fully comply with the requirements for traceable verification according to DIN EN ISO 9001:2008, Section 7.6a, "Control of monitoring and measuring equipment." The instruments provide a self-diagnostics coverage of 94% or higher (in accordance with IEC 61508), and very low rates of undetected failures.

Supporting software

With smart instruments, data are no longer just the primary process variables. They also include secondary process variables, sensor health, sensor performance characteristics, calibration information and realtime diagnostics. All this extended information can be used to improve the process, optimize instrument performance, extend instrument life and maximize productivity of maintenance personnel.

But it has to be obtained and then be processed by supporting software. Fortunately,

FIGURE 3. WLAN, Bluetooth and Webserver interfaces allow technicians to monitor, diagnose and configure instruments from smartphone applications

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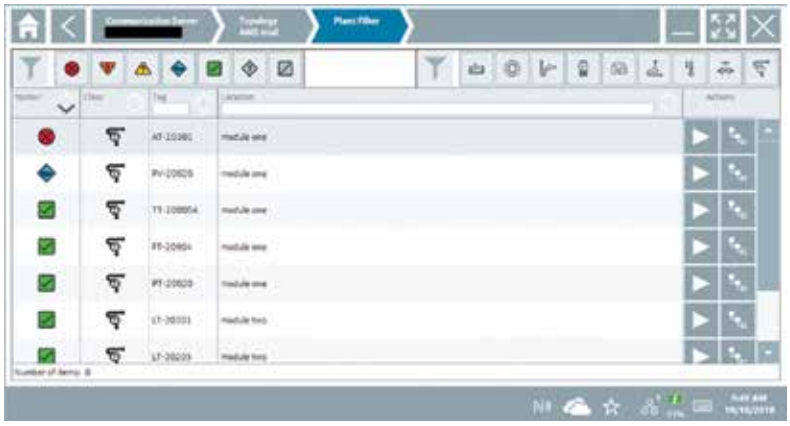

FIGURE 4. Display at a condition monitoring's HMI shows the equipment health status per NAMUR NE107

all major instrument manufacturers supply the necessary software.

Typically, the solution is a standalone system that does not interfere with the control system operation. It continuously monitors and logs instrumentation health status and makes that information visible to responsible persons so they can take action as required. In combination with smart sensors, it can run online self-checks and verifications to lengthen the calibration intervals, give insights about the installed base, and help identify critical devices (Figure 4).

Processing all the data from a plant's instruments can be challenging. For example, a chemical plant in Gendorf, Germany, has more than 4,000 instruments measuring level, flow, temperature, pressure and other primary process parameters. Attempting to employ the control systems for reading all the extended diagnostic information from all 4,000 devices, analyze it for problems, and issue instructions to the maintenance department would be a daunting problem.

Therefore, instrument manufacturers have developed specific software packages performing all those functions. The packages fall into two basic categories: instrument-management programs, which analyze realtime information from instrumentation; and asset-management software, which keeps track of every instrument in the plant and stores vital data, such as manuals and parts lists.

FIGURE 5. Instrument data from asset-management software can be accessed from workstations or handheld devices

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While a particular instrument manufacturer can provide information for its own instruments, what about all the other instruments in a plant from different manufacturers? Fortunately, standardization across the instrumentation industry makes that information available.

Device description (DD), enhanced device description language (EDDL), device type manager (DTM), HART and fieldbus configuration files are available from all manufacturers and can be accessed easily from various web sites, and then loaded into the instrument management program. These definition files enable interoperability among various automation system and instrumentation vendors.

When a plant has thousands of instruments, keeping track of manuals, parts lists, audit reports, maintenance schedules and other information can be a nightmare. A maintenance asset-management solution gathers all this information, digitizes it, and makes it available to maintenance technicians via handheld devices or the control system's human-machine interface (HMI; Figure 5).

In addition to displaying instrument manuals, parts lists and compliance information, asset-management software tracks all instrument activities, including calibrations, verifications and maintenance performed to meet various industry and government regulations. The software can also produce audits and regulatory reports meeting government and industry standards.

The asset-management software also provides maintenance management. That is, it determines when instruments need to be serviced, calibrated or verified, and notifies maintenance staff. The software can share data with other maintenance management programs, historians and spreadsheets. ■

Edited by Gerald Ondrey

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The Role of Frequency in Radar Level Measurement

No single frequency is suitable for all applications in the CPI. Understanding the principles behind the technology will help in selecting the right device

Jonathan Pradel
Krohne Group

IN BRIEF

RADAR TECHNOLOGY

SIGNAL DYNAMICS AND BANDWIDTH

FOCUSING AND ANTENNA SIZE

REFLECTIVITY AND FREQUENCY

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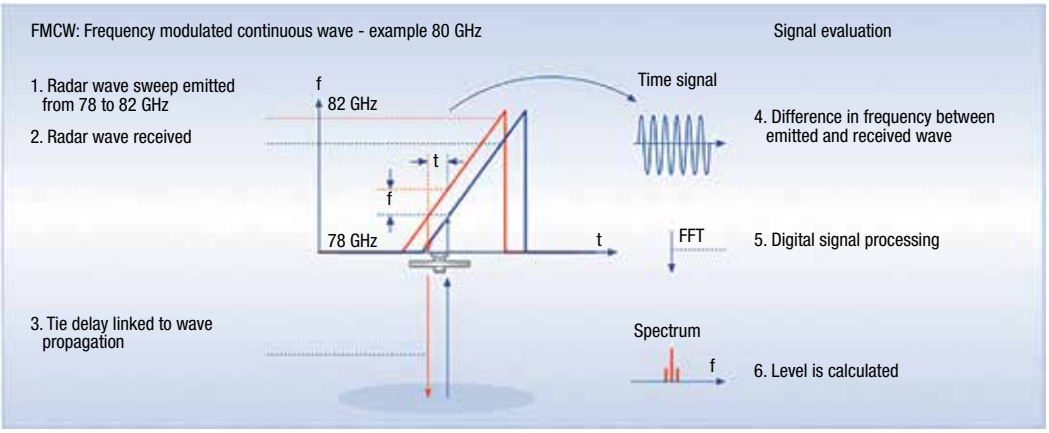

FIGURE 1. The measurement principle of FMCW radar technology is shown here

Radar has proven to be a reliable technology for level measurement in silos and tanks. However, there have been discussions recently about the capabilities of high radar frequencies: 80 GHz is often called a universal talent for all applications. But does this apply without restriction? Will all previously used frequencies be replaced? To answer these questions and to understand the possibilities in general, some background knowledge about radar technology is required.

Radar technology

There are two types of radar used for level measurement: pulse radar and frequency-modulated continuous-wave (FMCW) radar. Today, FMCW is the favored technology that all major industrial process instrumentation manufacturers rely on.

In FMCW devices, radio waves whose frequency is modulated over a bandwidth are continuously emitted, and the reflections are collected by a receiver. The difference between a transmitted and received wave of a given frequency is measured, and that is proportional to the distance to the surface at which it was reflected (Figure 1).

Thus, the level measurement by radar is primarily a non-contact distance measurement from the measuring device (mounted on top of the vessel) to the surface of a medium to be measured. By entering the vessel geometry and medium properties, such as density, the device can calculate level, volume or mass. In contrast to ultrasound, radar is independent of pressure and temperature. Viscosity and density do not affect the measurement. Despite this insensitivity, there are some factors that do have an influence on FMCW measurement, which are briefly described in this article to help find the best device for a certain application.

Signal dynamics and bandwidth

As each emitted frequency is reflected, a large received spectrum results is created. However, waves are reflected not only by the medium, but also by all surfaces in a vessel, including tank internals. The exact differentiation of all targets detected by the radar is only possible via a high signal dynamic, also known as high measuring sensitivity: the more signals reflected by a target that can be received by the device, the clearer or higher this point rises in the spectrum over the noise, and can be identified. This high dynamic is given by most FMCW

devices available on the market.

As the bandwidth of the radar widens, the resolution of the fast Fourier transform (FFT) spectrum increases and the individual targets are indicated by narrower, more accurate peaks. The bandwidth over which the frequency is modulated determines the number of different signals reflected from a target. A 24-GHz radar device typically modulates between 24 and 26 GHz and thus has a bandwidth of 2 GHz, while an 80 GHz typically modulates in the range between 78 and 82 GHz and thus has a bandwidth of 4 GHz. With 4 GHz, for example, it is possible to differentiate between targets that are only 10 cm (4 in.) apart. With 2 GHz, these targets cannot be distinguished under the same conditions.

As a side note, the ability to distinguish close objects does not (yet) include the possibility to do interface level measurement. For the moment, only time-domain reflectometry (TDR) guided radar (with radar waves guided along a cable or rod) is able to differentiate two different levels of product inside one tank.

Focusing and antenna size

For a long time, the bandwidth was limited by the performance of the microchips that were available. Today, the bandwidth is limited by the antennas and their designs that have to transmit the frequency spectrum. Radar waves do not propagate point-focused like a laser signal, but rather in the form of a lobe or angular beam (Figure 2). In order to influence the opening angle or the focusing of the angular beam, there are two possibilities. First is the frequency used: the higher the frequency, the smaller the aperture angle due to the shorter wavelength. The angular beam width of an 80-GHz system with 4 GHz bandwidth at 10 m (33 ft) distance is only 30% as wide as that of the 24 GHz with 2 GHz bandwidth (0.5 to 1.75 m or 1.6 to 5.7 ft). The second possibility is the antenna diameter: the larger the diameter, the more focused is the angular beam.

For the chemical process industries (CPI), this can be easily transferred to several possible areas of application: in high narrow silos, the radar beam should not come into contact with the silo wall or tank internals, since both should not be measured. Therefore, the radar an-

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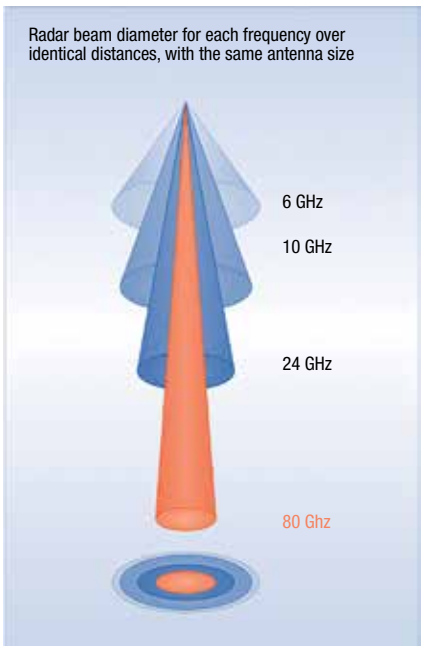

FIGURE 2. Radar waves do not propagate point-focused like a laser signal, but rather in the form of a lobe or angular beam. The width of the beam depends on the frequency

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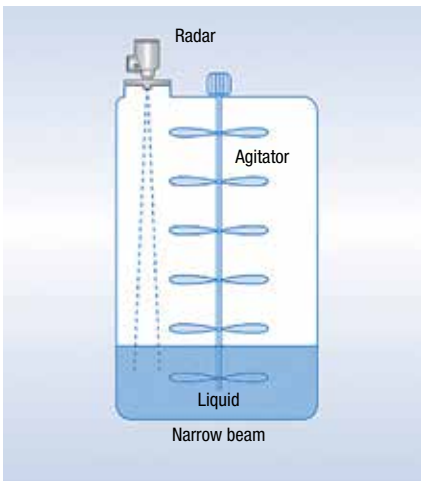

FIGURE 3. High signal focusing is also an advantage with internal obstructions, such as agitators

Krohne

FIGURE 4. This 80 GHz radar gage with PEEK lens antenna has an extremely compact design

gular beam must both be focused and kept as narrow as possible, as provided by an 80 GHz radar gage with a large antenna. In other applications, the strong focus does not make sense; for instance, in tanks with moving surfaces, or if the signal does not meet at right angles with a flat liquid surface due to the flange not being mounted horizontally. A very small opening angle would be counterproductive because the radar waves reflected at the product surface would not return to the antenna, hence no signal evaluation is possible. Here, a 24 GHz device with a small antenna is the better choice.

Reflectivity and frequency

In addition to the angle, the properties of the product surface also determine how many radar signals are reflected and how they are received: the higher the reflectivity or dielectric constant (*Er*), the higher the amplitude of the reflected signals. Liquids reflect very well: water with an *Er* value of 80 is one of the most reflective products, with about 65% of the emitted energy and signal received back. Acids and alkalis with an *Er* value of 20–30 reflect approximately 40% of the signals. Liquid hydrocarbons with an *Er* value between 1.6 and 3 will reflect 5% of the emitted energy even at a low radar frequency of only 10 GHz, which is sufficient for a measurement. An 80-GHz radar would also work well in this application.

In contrast to liquids, bulk solids generally reflect very poorly: radar transmitter manufacturers state an *Er* value of approximately 1.4 as the lowest value that can still be measured reliably and safely. While the reflection coefficient of a flat liquid surface does not change with the frequency, the backscattering on fine-grained bulk goods, such as granules or powders, increases significantly with a higher frequency. The 80-GHz radar is therefore the first choice here, because of the high dynamics it is able to clearly display the level line, even in the case of a heavy dust development (for example, during the filling process of a silo or stock pile). The better resolution of its 4 GHz bandwidth also helps to distinguish the signals from interference and medium, even if they are close together.

This completes the description of the main parameters of FMCW radar level measurement. The antenna design, as well as its position and orientation, were only briefly described, since both are strongly application-dependent. It should now be clear that there is no universal frequency for all applications. In the following, typical cases and application recommendations are briefly shown. They will guide you in the right direction, but will not replace a detailed evaluation of your application by an expert who can guide you to find the right combination of frequency and antenna type suited for your application.

- A 6-GHz radar gage is the first choice for reference vessels or bypass measurements: it provides a good signal in a still pipe, the angular radar beam experiences no further expansion due to the impermeable wall of the vessel. 6-GHz devices are only partially suitable for use in free-field or in a regular tank
- 10 GHz is an ideal frequency for applications with simple storage or process tanks up to a maximum height of 30 m (100 ft). Up to about 40 bars and 150° C, small and cost-efficient plastic antennas can be used, but due to their length, they protrude relatively far into the measuring range. In most cases, large metal antennas of size DN150–200 (6–8 in.) and corresponding flanges are required
- 24 GHz is a good all-around frequency for liquids as well as for bulk solids. Its areas of application are process vessels in the chemical industry with agitators, pumps, highly agitated surfaces (Figure 3), and operating at high pressures and temperatures. The metal horn antennas of size DN50–80 (2–3 in.) typically used here are already significantly smaller than those used for the lower frequencies. As an alternative, plastic drop antennas are available in various designs, for example, the drop antenna as a closed antenna system for dusty atmospheres will withstand deposits
- 80 GHz is the frequency with the highest focus and is best suited for tall and slim containers in order to avoid interference reflections. In addition, the short wavelength is reflected very well, this is especially advantageous for bulk solids, even with granules and powders with very small particle sizes or high dust levels. Another advantage is the high signal focusing by design that needs no additional focus from a large antenna: the flush-mounted plastic (polyether ether ketone; PEEK) lens antenna type is sufficient and very popular in these applications (Figure 4). Due to the small size, it can be used with threaded connections that sometimes make the flange obsolete and may save a lot of money. 80 GHz has an enormous measuring range with a small dead zone, the vessel can be filled almost up to the antenna

Further information can be found in Ref. 1. ■

Edited by Gerald Ondrey

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Key Questions to Guide Effective Selection of Personal Protective Equipment

Armed with a proper understanding of chemical exposure risks and available safety solutions, engineers can be confident in selecting the best personal protective equipment to provide reliable barriers to workplace hazards

Paul Bryce
Ansell Chemical Solutions

There is a tendency to think about personal protective equipment (PPE) in the workplace in the abstract — as a requirement to be checked off, rather than a critical component of worker safety and often the last line of defense. Most organizations care deeply about safety, of course, but their understanding of PPE — especially PPE designed to protect against chemical exposure — can be limited.

That is a problem, because different chemicals react differently to different PPE materials, and even today, there are examples of well-meaning companies that provide the wrong PPE to workers handling various types of dangerous chemicals. Just last year, there was an incident in which a manufacturer discovered a gap in its PPE program only when workers suffered adverse effects, believed to be because of exposure to chemicals in the workplace. It was a costly mistake, resulting in significant fines from the Occupational Safety and Health Administration (OSHA; Washington, D.C.; www.osha.gov) and an overhaul of the company's PPE program and other related safety and occupational hygiene protocols.

This type of situation is not unusual, and it is easy to understand why. There are anywhere from 25,000 to 84,000 chemicals in use in the U.S. today, and this wide range is indicative of the difficulty the industry faces in tracking and cataloguing chemicals that are in active use. Imagine the challenge facing employers — they know they need chemicals with certain properties to produce their products, but the universe of chemicals is vast, changing every day, and those chemicals have diverse properties and present different risks in the workplace. Although the challenge to select the proper chemical PPE is daunting, it is certainly not impossible. This article provides some guidelines to help in the selection of PPE for chemical processing facilities.

FIGURE 1. Chemical PPE must protect against different combinations of chemicals, and often a single PPE solution that protects against one chemical may not provide protection against another chemical

Where to begin

There are some basic questions employers should ask when putting together a chemical PPE plan as part of their hazard risk assessment program, with the answers providing a reliable roadmap to optimal safety for their workers.

What are the chemical hazards? This seems simple, but it is far from it. Many work environments have multiple individual chemicals and combinations of chemicals (mixtures), and PPE providing protection from one chemical may not protect from others (Figure 1). Certain PPE materials provide effective protection against specific chemicals. Table 1 provides some common examples, but employers should consult with a manufacturer before choosing any PPE. Having a thorough inventory of chemicals that are present in a workplace is critical to ensuring appropriate risk assessments are in place, with appropriate worker-exposure prevention measures in place, including PPE. From there, it is important that any potential cross-exposure for multitasking employees is understood and accounted for in the PPE plan. Maybe that means different types of PPE, or maybe it changes the way workers approach various tasks, but the goal is to avoid unexpected exposure for workers who believe they are protected.

It is critical to remember that there is no single product that will protect a worker against all types of chemical hazards. Safety managers must therefore be experts in their work environments and provide the appropriate PPE for every given situation. Sometimes, the appropriate

TABLE 1. COMMON MATERIALS USED IN CHEMICAL PPE	
Natural rubber (latex)	Natural rubber latex provides excellent protection from bases, alcohols and dilute water solutions of many chemicals, with fair protection against aldehydes and ketones
Polyvinyl chloride (PVC)	PVC protects against strong acids, strong bases, salt solutions and some heavy organic chemicals
Nitrile (Buna, NBR)	Nitrile rubber protects against oils and greases (including animal fats), xylenes, perchloroethylene and aliphatic solvents. It also protects against most agricultural pesticide formulations, some biological materials, as well as additional chemicals
Neoprene	Neoprene protects against a broad range of oils, oxidizing acids (nitric and sulfuric), polar aromatics (phenol and aniline), glycol ethers, oils, greases and many other chemicals. Note that other materials may offer better protection against some of these chemicals
Butyl	Butyl rubber protects against moderately polar organic compounds, such as aniline and phenol, glycol ethers, ketones and aldehydes
Polyvinyl alcohol (PVA)	PVA provides a high level of resistance to many organic chemicals, such as aliphatic compounds, aromatics, chlorinated solvents, fluorocarbons and most ketones (except acetone), esters and ethers
Viton	Viton protects against aromatics, chlorinated solvents, aliphatics and alcohols
Sealed-film (laminate)	Laminate is one of the most versatile materials available and protects against many chemicals and biological materials

PPE can consist of multiple pieces of equipment, such as protective clothing, facemasks, gloves, boots and so on (Figure 2). Proper protection may also demand additional performance requirements, especially where there are secondary hazards, such as heat and flames, or explosive atmospheres to consider. It is not uncommon to see workers in complex chemical environments utilizing multi-hazard or multi-risk PPE to ensure they are protected against all hazards.

What are the physical hazards and needs of the working environment? It is easy to get lost in the complexity of chemical protection, but the reality is the risks to workers are not limited to chemical exposure. What are the threats for abrasion, exposure to heat and flame or extreme temperatures, or tears or punctures to protective clothing? Even a perfectly matched chemical protective suit is ineffective if it has a hole in it. There are solutions for

FIGURE 2. In complex chemical-processing operations, many pieces of PPE may be required, from specialized gloves to facemasks or full-containment suits

FIGURE 3. Knowledge about exposure risks is crucial in selecting the best PPE for a particular situation. For instance, considerations must be taken for chemical sprays versus a light splash, and if the chemical is in the liquid, solid or gaseous form

multiple hazards — sometimes all-in-one PPE solutions, other times layered protection. The first step is understanding all the risks.

How are the workers exposed to the chemical? This is an important and often overlooked consideration. PPE selection can be different depending on whether the chemical is in liquid, particulate or gaseous form, and if the potential exposure is brief or extended. Exposure to saturating liquid spray for example, versus a light splash, presents a different challenge for PPE and therefore must be considered as part of the risk assessment (Figure 3).

Next to the nature of the chemical, exposure time is one of the greatest determinants of appropriate protection. When assessing the effectiveness of PPE as it relates to exposure time, it is important to understand its performance in terms of chemical penetration and permeation. Penetration is the movement of large and likely visible quantities of chemical through a PPE material and can occur by movement of the chemical through a hole or a faulty seam, for example. Permeation is the process by which very small and likely invisible quantities of chemical pass through the protective material on a molecular level (typically in microgram quantities). It can be measured as a benchmark relative to other PPE in terms of permeation rate (how fast the chemical passes through the PPE material) and normalized breakthrough time (the time taken to reach a specified permeation rate, enabling different test laboratories to test to the same threshold).

The normalized results of penetration or permeation tests are used to assist health and safety managers in their selection of the relevant and appropriate PPE for their application.

What are the physical effects of chemical exposure? There are many chemicals today that are used in varying forms depending on the chemical or chemical formulation (such as solid powders, dispersions, liquids and liquid mixtures, gases that may be pressurized and so on). Many of these chemicals have the ability to cause significant harm that can occur through skin contact, inhalation or ingestion if the correct PPE is not used. Depending on the nature of the chemical hazard, noticeable effects from exposure may take years or even decades to become apparent and may be life-threatening or indeed life-limiting. Therefore, in order to prevent occupational injuries or diseases that may not become known until much later on, it is important for health and safety managers to seek support from manufacturers and other experts to understand the required PPE needed to protect their workforce.

Will the use of PPE introduce new workplace hazards? Could the use of PPE increase the likelihood of musculoskeletal injuries or conditions due to changing the way the worker moves while performing a task? Could it weaken a worker's grip, putting the worker and others at risk? One common issue is workers wearing PPE that impacts their performance or simply is not comfortable, which too often prompts them to remove the gloves, mask or suit out of frustration.

This is common and is especially prevalent when the mindset is "the heavier or thicker the product, the greater the protection." That simply is not true in many cases and becomes counterproductive as workers reject the too-heavy suits or gloves. When that happens, they too often remove their PPE in hazardous environments, as the equipment is perceived to be more of a hindrance than help. Effective PPE selection is about comfort and performance every bit as much as it is about protection.

The answers to these questions will help in choosing PPE materials, as well as with other decisions, such as whether the equipment required should be reusable or disposable — or, as they are often called, limited-use apparel. In apparel, there are indications that industry is moving more toward the use of disposable suits, because the materials are often lightweight, flexible and provide broad protection from multiple chemical and secondary hazards. That said, reusable technology still has its place in the market and there are environments where a typically higher initial investment is worthwhile, either on the basis of physical performance or strength, or in terms of total cost of ownership versus disposable or limited-use solutions. This is true especially if the suits are required to be worn frequently and appropriate cleaning techniques and storage are available.

Regulations and standardization

PPE selection does not happen in isolation. There are a number of external factors that contribute to organizational decisions about workplace safety and PPE, and there are trends across the industry that influence PPE program decisions, as detailed below.

Vendor standardization and consolidation. Between suits, gloves, goggles, boots, helmets, respiratory equipment and countless other safety solutions, navigating PPE selection can be a seemingly complicated process. However, there can

be benefits to working closely with a vendor that can provide multiple PPE solutions, thus reducing the complexity of PPE that may be used on site and focusing on a core selection of compatible PPE specifically designed for the hazards to be faced.

Global standardization and regulatory considerations. This is a complex challenge. There are different standards and regulations in different countries and regions around the world. Businesses may benefit from working with a vendor that can support their PPE needs for workers in facilities around the globe. Such vendors may offer PPE products that provide the same consistent levels of protection while also complying with different regional regulatory requirements.

Safety managers should remember that industry standards and regulations are moving targets. In 2017, updates to the European standard EN 374 introduced significant adjustments to standards that had remained unchanged since 2003. These updates were necessary because the chemicals used in the workplace and chemical-resistant PPE technologies both had evolved over time.

EN 374 was a series of standards providing guidance on testing methodologies and requirements for gloves used when working with chemicals and microorganisms. The updates improved worker safety and were adopted internationally, at which point they became EN ISO 374. These kinds of updates may not happen quickly, but they are important and require close attention from safety managers.

Resources for PPE selection

Employers are responsible for accurately evaluating workplace risks and securing the right PPE for their workers, but, as previously stated, they do not have to do it alone. The most responsible PPE manufacturers offer resources to help companies through the process of building a safety program and selecting the right PPE. At their best, these programs are collaborative processes that can provide substantial value to the company and better PPE options to the workers.

There are third-party resources as well. OSHA offers guidelines and tools to help employers develop a safety program and choose the appropriate PPE, as does the European Commission.

Chemical protection is complicated and is a significant challenge, even for responsible, safety-conscious employers. The right solutions for a range of applications are available, and responsible vendors offer tools to help safety managers find PPE that best safeguards their workers. ■

Edited by Mary Page Bailey

Author

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AUMA Riester

Sulzer Chemtech

AchemAsia — International Expo and Innovation Forum for Sustainable Chemical Production — is the international technical and scientific exhibition and conference for the Asian market. With about 400 exhibitors from some 20 countries, it focuses on the exchange of experience between scientists and engineers, as well as between equipment suppliers and users. Taking place every three years, this edition of AchemAsia runs from May 21–23 in Shanghai. It is organized by Dechema (Frankfurt am Main, Germany; www.dechema.de) and CIESC (Chemical Industry and Engineering Society of China), in cooperation with numerous Chinese and international partners.

Apart from the move to Shanghai, where AchemAsia will take place at the National Exhibition and Convention Center (NECC) for the first time, participants can look forward to a couple of novelties: The International Expo and Innovation Forum for Sustainable Chemical Production brings the latest technologies in this field to the spotlight. Making the chemical process industries (CPI) more sustainable means using less resources and less energy. Efficiency in production processes is increased via the implementation of energy recovery measures, the use of better catalysts and optimized equipment. It means designing processes with a holistic perspective, making use of new digitalization and modeling approaches. It means protecting scarce water resources through state-of-the-art industrial water management, closing loops, culminating in concepts such as zero liquid discharge, where no water leaves the industrial process.

Besides being showcased in the exhibition, these trends will also be discussed in the accompanying congress. Composed of satellite symposia on hot topics of the Chinese CPI, the congress takes place right in the exhibition hall.

The following is a sample of products being exhibited at AchemAsia 2019.

This variable-speed actuator is also explosion proof

This electric-actuator manufacturer is showcasing the latest advances in valve actuation at this year's AchemAsia. The new SAV variable-speed actuators bring significant advantages to challenging valve automation tasks, because each change of valve position can be done at the optimum speed. These actuators are now also available in explosion-proof versions. High operating speeds favor rapid opening and closing. Low speeds give the best positioning accuracy, which considerably increases the effectiveness of control valves. Reducing operating speeds close to the end positions avoids pressure peaks in pipelines and protects the mechanical integrity of valves and sluice gates. Hall 7.1, Stand F26 — *AUMA Riester GmbH & Co. KG, Muellheim, Germany*
www.auma.com

AR and VR reshape the reality of the process industry

This company will be showing advanced augmented reality (AR) and virtual reality (VR) experiences that will allow visitors to have a closer look at equipment, as well as how it integrates into industrial plants (photo). As a leader in separation and mixing technology, the company is well-aligned with the theme of this year's event — sustainable chemical production in China. To support this, the company will showcase real-world applications of its separation technologies, for example for bioethanol production. Using tablets with the company's AR application (app), visitors will be able to interact with 3-D models of facilities, where they will see how its equipment fits into large-scale processing plants, as well as accessing relevant information on the products, in the form of text, videos and pictures. A VR app will also allow visitors to explore the comprehensive range of static mixers and column internals, including the next-generation random packing NeXRing. In addition, a VR headset will be available at the stand to virtually walk through a number of process plants featuring the manufacturer's solutions. Visitors to the stand will be guided through these experiences by industry experts, who will also be available to discuss their key mass-transfer solutions for process manufacturing. Stand B3, Hall 7.1 — *Sulzer Chemtech AG, Winterthur, Switzerland*
www.sulzer.com

New versatile pneumatic swivel actuator for automating valves

bar pneumatische Steuerungssysteme

The bar-agturn (photo) is a new pneumatic swivel actuator that covers the full spectrum of torques and swivel angles for shut-off device automation, with 18 different sizes at torques from 2 to 13,040 Nm. The actuators also cover a wide range of application options thanks to actuator versions with different swivel angles. The high-grade powder-coated covers and housing coating made of hard anodized aluminum enable use even under aggressive environmental conditions. Precisely cut piston teeth ensure smoother running, optimal torque and low wear. The flange patterns and air connections are marked this way to ensure unmistakable allocation. The use of the same covers for single and double-acting actuators enables conversion from single to double-acting versions (or vice-versa) without having to replace the caps. A standardized VDI/VDE 3845 interface allows all positioners and end-switch boxes widely available on the market to be attached. The integrated position indicator is equipped with variable clips to display the valve position, thus reducing costs for the user. In most cases, two ISO flange patterns are available for each size of actuator for flexible automation of valves. The pinion, with its octagonal connection, adapts a parallel or diagonal operating-shaft orientation for the valve and ensures space-saving actuator installation. Optimal valve adjustment is achieved by setting the end positions in the 0 and 90 deg position from 5 to –5 deg. Stand D89 (German Pavilion) — *bar pneumatische Steuerungssysteme GmbH, Dattenberg, Germany*
www.bar-gmbh.de

Krüss

Analyze surface roughness and surfactants with these devices

Two highlights being exhibited at this company's stand are a surface-roughness analyzer and a bubble-pressure tensiometer. The Surface Roughness Analyzer (SRA) supports the optimization of materials or production process that require a surface that must be very smooth, show a certain texture or

voestalpine Böhler Bleche

Samson Controls

Richter Chemie-Technik

Flux-Geräte

a required degree of roughness. The SRA gives users a 3-D image of a sample's surface and provides data that exactly describe its topography, quickly, without contact and with an extremely high resolution. Also on display is the Bubble Pressure Tensiometer (BPT) Mobile (photo, p. 61) — a hand-held device for quality control of cleaning and coating baths. Users can simply immerse, click, and read out the surfactant content of a parts-cleaning bath within seconds. The device is based on surface tension measurements, and an ad hoc evaluation of the data informs the quality control inspector if the bath is okay. Moreover, for proactive adjustment of the bath, the BPT Mobile shows how the surfactant content decreases over time due to removed parts, for example. Hall 7.1 Stand D60 — *Krüss GmbH, Hamburg, Germany*
www.kruss-scientific.com

Plates and sheets of a variety of metals and alloys

This company is a manufacturer of single cross-rolled sheets and plates of special materials. Austenitic and super-duplex stainless steels, nickel and nickel-based alloys, as well as high alloyed special steels are the standard product portfolio. Titanium and titanium-alloy sheets and plates (photo) have now been included into the production program to increase the available product range. As the only titanium-producing European rolling mill, CP titanium Grade 1–4 and alloyed titanium Grade 5 are being offered and produced for applications in industrial, medical and aerospace applications. In addition, other titanium alloys for special applications can be offered upon request. At AchemAsia, the manufacturer will present its standard products, recent investments into their manufacturing technology and new titanium products, along with their advantages for applications in chemical process industries. Hall 7 Stand E34 — *voestalpine Böhler Bleche GmbH, Mürzzuschlag, Austria*
www.bohler-bleche.com

A new generation of valve positioners

The new positioners for 4–20-mA applications combine the latest technological developments with the proven device base from the Trovis Type 3730-1 and Type 3730-3 predecessor models (photo). Both positioners are particularly rugged thanks to their no-wear, non-contact travel-sensing system. Two inductive limit contacts are available to reliably indicate both valve end positions. At the same time, the positioners' air consumption has been reduced considerably by upgrading the pneumatics block. — Stand D49 (German Pavillion) — *Samson Controls (China) Co. Ltd., Beijing, China*
www.samson.de

A rupture disk for applications with strict hygiene requirements

To achieve constant monitoring of the rupture disc, the KUB clean is also available with integrated signaling. Both rupture disc and signaling have only one installation point and can be easily integrated into the process control system. The absolute leak-tightness and durability of the KUB clean ensures perfectly hygienic production with a working pressure ratio of up to 98%. Furthermore, the extreme robustness ensures a very long service life and low downtimes. Stand C85 (German Pavilion) — *Rembe GmbH Safety + Control, Brilion, Germany*
www.rembe.de

This magnetic drive pump meets local Asian standards

The QMD series of magnetic drive pumps (photo) were designed to anticipate the fast-growing Asian market. This newly developed pump series was launched in 2018. The pump series complies with the requirements of the local standard GB 5662, which can be equated with ISO 2858, and is designed for applications in the temperature range of –10 to 100°C. The excellent chemical resistance provided by fluorinated ethylene propylene (FEP) lining and other high-quality materials, such as silicon carbide, allows for opera-

tion in applications with a performance range up to 125 m^3/h and 65 m head. A total of eight pump sizes are available. Stand C61 (German Pavilion) — *Richter Chemie-Technik GmbH, Kempen, Germany*
www.richter-ct.com

All types of pumps for fluid transfer in containers

This company's drum and container pumps (photo, p. 62) are available in a variety of designs and materials, which can be tailored to users' requirements. This includes pumps with and without mechanical seals, mixing pumps, explosion-proof or 3-A certified versions and food pumps. Moreover, all pumps can be combined with various motors. In this way, media can be pumped out of vessels with sizes ranging from small cans to intermediate bulk containers (IBCs). The drum and container pumps are suitable for pumping various low-viscosity and also especially aggressive and highly flammable fluids. The axial-impeller pumps provide a pulsation-free pumping action. Constructed in a modular design, different pumps are able to be driven by the same motor. As a result of their low weight, the pumps can be easily carried from container to container. The easy handling of motor and pump keeps changeover times short. Stand C86 (German Pavilion) — *Flux-Geräte GmbH, Maulbronn, Germany*
www.flux-pumps.com

A stirred reactor for industrial photochemistry

The new stirred photoreactor (photo) allows syntheses using the energy of light and an advanced stirring technique that ensures high circulation rates in the reactor. The concept of this new stirred reactor is ideal for multiphase reactions involving liquids, gases and solids. It combines high productivity and flexibility with the safe operation of immersed light sources. Reactors up to 50 m^3 are realized with this proven design, and a reliable scale-up by this company's specialists enables further reactor sizes. These photoreactors can be manufactured from numerous material variants. Common materials are: enameled steel, stainless steels, nickel-base materials or titanium. Stand B95 (German Pavilion) — *Ekato (Shanghai) Agitation Equipment Co., Shanghai, China*
www.ekato.com

Ekato

Gerald Ondrey

Engineering Internships: A Win for Students and Companies

Insights to the benefits of internships for both students and the employing companies are discussed

Carl Rentschler
Consultant

Internships have become an important part of the professional landscape. Both students and companies in the chemical process industries (CPI) benefit from the relationship. For students, it is a great way to gain hands-on experience and supplement their engineering education, while starting to build a resume (Figure 1). The experience also provides an assessment of different technical areas that may provide focus when the student is seeking a long-term job.

For companies, internships provide needed labor for lingering tasks that are often pushed aside during a busy production schedule. Interns may, for example, be able to automate tasks that are unnecessarily cumbersome. CPI companies are also able to assess interns as possible candidates for long-term employment. Internships take effort on both sides to be productive, but the overall benefit for students and companies is immeasurable and can be a win-win relationship.

An internship, as discussed in this article, is a temporary work assignment for students that typically occurs during the summer break, but may take place at other prescribed time periods throughout the school year. Interns are generally paid an hourly wage and work in areas relevant to their engineering education. An earlier article written by the author, "Career Guidelines for Young Engineers" [*1*], stresses many of the key points that engineering students should focus on as they pursue an engineering career. This article provides additional information, specifically about internships. By mentoring students, the author has gained valuable insight into the benefits and challenges of students pursuing internships. Through a 44-year engineering career, he has worked with countless interns and knows the upside of working with these students in a corporate setting. This background provides an excellent foundation for providing a viewpoint on internships, a key aspect of engineering training and company staffing.

FIGURE 1. Interns can obtain valuable hands-on experience and supplement their engineering education, while starting to build a resume

Company benefits

As companies take on their engineering workloads, it is strategically wise to assign work based on difficulty and engineer capability. It is not very efficient to have the more experienced engineers doing common-place tasks. Internships offer the possibility for the more routine tasks to be assigned to students with a solid technical base, but limited technical depth. From a commercial standpoint, this is most efficient and can preserve limited budgets. Interns are able to perform routine tasks with limited guidance and are able to learn engineering techniques in the process.

While interns may not offer the technical depth of experienced engineers, they do provide the opportunity to introduce innovations to companies. These may result from their coursework revealing more efficient computational techniques, or from information technology (IT) techniques that may be new. Students tend to stay abreast of technology changes and often have an interest in this area. It is a natural fit for interns to assist a company in automating tasks. For example, it has been the author's experience that interns can add significant value by developing computational spreadsheets or tracking tools.

Internships offer companies the possibility for off-line focus groups to address lingering issues or to devise process improvements. Generally, full-time staff is consumed with ongoing work and cannot devote time to step aside to assess and modify processes. Interns provide the opportunity to interject unbiased viewpoints and manpower to address off-line issues. One possibility is to bring together a few interns under the guidance of an experienced engineer and allow them controlled reign to assess situations. The end

result of such an exercise is a report by the intern(s), and often a presentation to staff. This is a great benefit to the company, and offers considerable training to the students.

Finally, internships offer companies the opportunity to assess the capabilities of potential long-term hires (Figure 2). By witnessing the daily performance of students, companies go beyond a snapshot of a candidate and get an in-depth view of their capabilities. The author's experience is that some of the best hires have come through internships. These new hires are schooled in company processes and can be productive as soon as they join the company following graduation.

The student perspective

An engineering education covers the breadth of technical topics that are necessary to become an effective engineer, but training is not complete until experience can be realized. The most effective means to do this is to engage in internships during breaks in coursework. This allows students to apply academic coursework, and to gain insight into the professional life of an engineer. The interaction of peers and working as a team is generally not covered in the classroom. This is key to be effective in the engineering profession. An internship also permits the student to enhance communication skills, which are crucial in the workplace.

The author's intern experience many years ago allowed him to get a much needed look at the real world of engineering. This experience made him realize how important a good education foundation is, but also emphasized the need to shift gears to work in a team environment. As opposed to the classroom, the work environment stressed the need to deal with inputs of others, and to provide timely outputs to others. Schedule, quality and budget received the focus he never saw in school, and this became a foundation throughout his career. Now, in mentoring students, providing focus on internships is the hallmark of any advice he provides to engineering students.

One of the great benefits of internships is the ability to look at different technical areas and develop insight into the area that a student may prefer upon graduation. Ideally, multiple internships are possible during a student's education, and with each, the student should strive to work in a different area. For example, perhaps on a first internship the student can work in a design office, and then with a later internship work in construction in the field. The more variety that is achieved through internships, the greater cross section a student will have in choosing his or her career path within the engineering discipline. Finding a path that fits each individual can be vexing, and the more data points that are available, the greater the chance that an appropriate career choice will be made.

The author has reviewed countless resumes of graduating engineers seeking that first job, and those that stand out are the ones that show experience (even though minor) in their field. Competition is

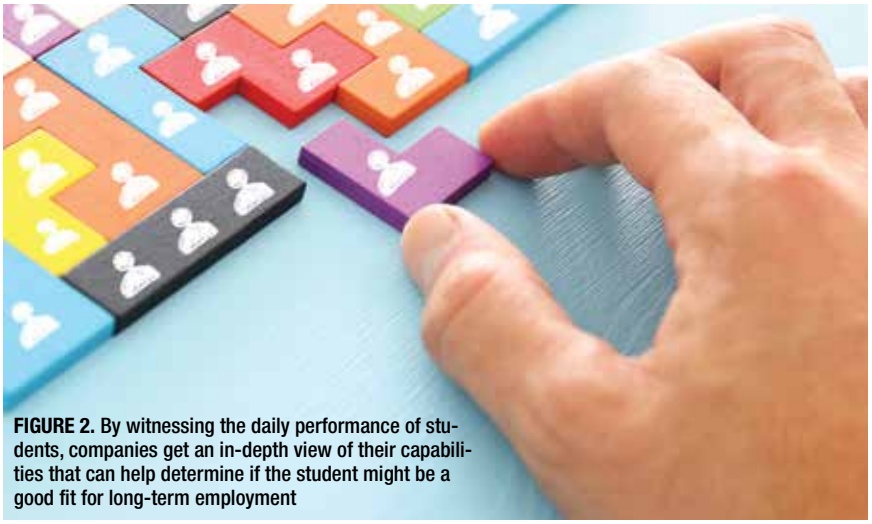

FIGURE 2. By witnessing the daily performance of students, companies get an in-depth view of their capabilities that can help determine if the student might be a good fit for long-term employment

intense for a first job, and graduates must make every effort to distinguish themselves. Scholastics are important, but companies are looking for candidates who have at least some level of workforce training. Internships provide that threshold experience. Interns should keep an open mind to the thought of being hired long-term by a company that has hired them temporarily. By going above and beyond on assignments, interns can distinguish themselves, and receive serious consideration for a long-term position.

Finally, internships allow the students to earn some much needed money. Costs are generally staggering for students and earning money along the way helps with these costs. However, even if the only internship available is non-paid, the author strongly urges students to consider such a position. Experience is valuable and a differentiator down the road upon graduation. Students concluding their freshman year may have limited opportunities for an internship, and an offer to work at no pay may result in an early prized internship.

Making the match

Finding that internship match between student and company may be a challenge (Figure 3). A first start is for students to utilize university career centers. Companies will generally post their intern openings, and often attend job fairs sponsored by the schools. There are also websites that focus on internships and these can be used to seek out numerous companies, even international opportunities. These websites can be identified by simply searching the internet for "engineering internships." The department leadership in an engineering school is also a source of internship placement, since sometimes they will be contacted with such opportunities.

In two articles the author noted the importance of networking in today's competitive job market [*1, 2*]. Constant networking is the new norm in the professional world, as the dynamics of finding and holding a job have been exasperated. Through school contacts, faculty, friends and possible mentors, there may be leads to potential internships. These relationships should be built, and the school days are a good time to start. Networking is a give-and-take process, so perhaps a student will hear of leads that will help a colleague, while also gaining information that may help him or herself.

Once opportunities are identified, students should focus on crisp resumes and thoughtful and brief cover letters. For people just starting a career, there may not much experience to include. However, a demonstration of previous work, even if not related to engineering, shows companies that there is a solid work ethic. Remember, competition is keen, so it is important to include facts that are differentiators. Highlighting how you are a good fit is important to set you apart. For example, perhaps you have completed special course work or projects that align with company business. If an interview is achieved, candidates should be sure to have full knowledge of the company. This can be gained via an internet search and should include awareness of core businesses, knowledge of major clients, approximate annual revenue and even management structure. The author has interviewed countless candidates, and those that demonstrate knowledge of the company distinguish themselves by showing strong company interest and how they will be a fit. ■

Edited by Dorothy Lozowski

FIGURE 3. Finding that internship match between student and company may be a challenge, but there are numerous resources available

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CHEMICAL ENGINEERING
Access Intelligence

Gulf Coast
special advertising section

Inside:

Andritz AG 78
CR Clean Air 70
Curtiss-Wright EST Group 71
Emerson 71
Endress+Hauser 76
Flexitallic 78
Flowrox Inc. 72
HarbisonWalker International (HWI) 79
Heat Transfer Research, Inc. (HTRI) 76
John Zink Hamworthy Combustion 73
Magnetrol 72
Milton Roy Company 77
Paratherm 79
Pyromation, Inc. 73
Quest Integrity Group, LLC 69
RedGuard 74
ROSS Mixers 70
Sulzer Chemtech Ltd. 74
Tekleen Automatic Filters Inc. 75
VEGA Grieshaber KG 75
Zeeco Inc. 77

Optimizing critical fired heaters is now easier than ever

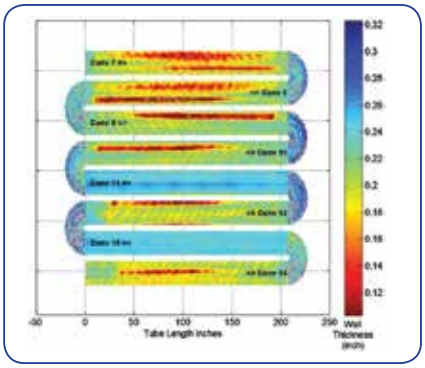
Quest Integrity provides industry expertise and engineering optimization planning and management to increase the life cycle value of fired heater assets

Unexpected asset failures present a number of complications to a facility, including costly repair and production interruptions. Historically, asset reliability and management methodologies have been reactive – only adjusting practices once a costly failure has already occurred. However, today's modern technologies allow operators to proactively manage their assets, mitigating many of the risks associated with premature asset failure. Significant improvements in technology innovation and reliability practices provide operators with life extension opportunities that were not available just a decade ago.

Quest Integrity understands that unique assets require unique solutions. Due to specific operator and individual asset requirements, a general model for asset integrity optimization is not an effective long-term solution. A powerful optimization management strategy should be specifically designed to address the current and future condition of the asset, achieving a higher level of performance and reliability, while decreasing the risk of unplanned shutdowns. Customized for the life-cycle of each individual fired heater asset, Quest Integrity's Fired Heater Optimization program consists of a multi-disciplinary inspection and engineering approach that includes tube creep and corrosion damage measurement and assessment, infrared thermometry (IR) data management, ultrasonic in-line inspection and remote digital visual inspection (RDVI). A variety of engineering assessments, including fitness-for-service, remaining life, risk assessment and failure analysis are utilized to significantly extend asset life, effectively managing cost and preventing catastrophic failures.

Depending on the condition of an asset, Quest Integrity's team of dedicated technical experts assist operators in determining the appropriate strategic action plan to ensure optimal performance and reliability of fired heaters.

Quest Integrity is a global leader in the development and delivery of asset integrity and reliability management services and solutions. The company's solutions consist of technology-enabled, advanced inspection and engineering assessment services and products that help organizations improve operational planning, increase profitability, and reduce operational and safety risks.



Ultrasonic inspection data indicating areas of severe wall thinning in fired heater tubing

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The Experts In Pollution Control Equipment

CR Clean Air has been providing custom engineered pollution control solutions to the CPI for over sixty years.

When it comes to your plant, you cannot afford downtime. Today having a comprehensive emission control program is more important than ever. Not only does it ensure the safety of your employees, it keeps the state out of your business. Systems installed in the 1990's when the Clean Air Act was last overhauled are probably not the Best Available Control Technology (BACT) today and let's face it - your process have probably changed over the years, not to mention expanded. When was the last time you even gave your pollution abatement equipment a second thought? Why wait until a permit is about to expire?

To make sure that your plant can operate at peak performance, why not call the experts today? The engineers at **CR Clean Air** have the experience to customize a wet scrubber fit for your plants needs. From acid gases such as HCL, to Ethylene Oxide to NOx and SOx emissions, if it can be scrubbed, we have probably scrubbed it. Our range of offerings, from jet venturis to packed towers, are available as standalone items, or can be supplied with peripheral equipment including liquid recirculation pumps and (when needed) exhaust blowers with or without a discharge stack. We also can provide instrumentation and control packages, from the simple to the complex.

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Remember – when it has to work the first time and every time, go with the leaders in pollution control technology.

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A classic mixing tool for the petroleum industry

Ross LPD Static Mixers are rugged, reliable devices that combine excellent inline mixing with minimal pressure loss

Ross Low Pressure Drop (LPD) Static Mixers are used throughout the oil and gas industry for turbulent-flow mixing applications.

Shown are removable LPD mixing elements supplied with retainer ring and flanged housing

These heavy-duty low-maintenance devices serve in continuous operations where high performance and accuracy are required, such as on-line water determination of crude oil; dosing of various additives into gasoline; blending different kinds of fuel oils; gas-gas blending; and pipeline reactions, among others.

Static mixers have no moving parts and the energy for mixing is available in the form of pressure. Pressure loss – a natural consequence of static mixing – sometimes becomes the deciding factor in mixer selection. The LPD Static Mixer remains a classic choice for many inline blending requirements due to its simple and durable design capable of uniform mixing with little pressure loss. The mixer elements consist of semi-elliptical plates carefully positioned in series to split and rotate the product 90 deg. in alternating clockwise and counterclockwise directions.

LPD mixers in diameters from 1 in. through 2.5 in. are welded to a central rod, while larger elements are welded to four outside support rods for maximum rigidity and stability. Units as large as 48 in. diameter can be supplied as stand-alone mixer elements or as modules complete with a mixer housing and injection ports.

Established in 1842, Ross is one of the oldest and largest mixing equipment companies in the world. Ross mixing, blending, drying and dispersion equipment is used throughout many industries in the manufacture of foods, adhesives, electronics, coatings, cosmetics, pharmaceuticals, plastics and composites.

www.staticmixers.com

A Flexible Solution to Better Visibility

Emerson's technologies make it easier for refining and petrochemical manufacturers to include compressors in operational performance improvements

Compressors operate at the heart of many refining and petrochemical production processes. Compressor performance impacts efficiency, safety, production, and energy usage. Today, many compressors operate as a standalone "black box" on a programmable logic controller (PLC). Such a configuration can limit potential for performance improvements driven by data integration and analytics—key digital transformation enablers.

Forward-looking organizations are continually evolving compressor control. These organizations are designing greenfield and modernization projects that integrate compressor control into the balance of the plant for total plant control and greater insight into performance.

Modern hybrid automation controllers such as the DeltaV™ PK Controller support digital transformation initiatives with compressor control capabilities. When well integrated, these systems can provide improved anti-surge control and optimization, better compressor and auxiliary device control, mechanical state and valve instrumentation diagnostics, maintenance procedures optimization and more.

Advanced technologies in the DeltaV PK Controller make it easy to gain visibility of compressor health.

- **Powerful Standalone. Easily Integrated.** The DeltaV PK Controller can operate as a standalone controller for compressors to fit the plant's current configuration and later be merged into a DeltaV distributed control system (DCS). Native integration into the DeltaV DCS and flexibility for OEM modular construction significantly reduce the engineering and mapping necessary with many PLCs. This provides capital project efficiency, while enabling operational performance improvements.
- **Future-ready technology.** Ethernet connectivity and a built-in OPC UA server allow the DeltaV PK Controller to provide advanced integration out of the box. Easily and securely connect to Industrial Internet of Things (IIoT) devices, cloud-based analytics, and third-party software for total plant control and insight into compressor performance.

- **Eliminate islands of automation.** Integration into the balance of the plant breaks down data silos, providing faster access to critical compressor health data and enabling operators to have insight into the total productivity and reliability of their plant.

An asset doesn't have to be miles away to be stranded. A compressor that cannot be integrated into the plant environment limits control and reduces productivity. Flexible control technologies like the DeltaV PK Controller can help you solve today's problems fast, while simultaneously preparing operations for digital transformation.

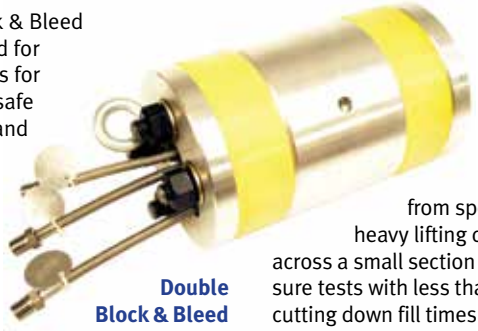
www.emerson.com/deltavpkcontroller

A Secure Isolation Solution for Hydrotests

Curtiss-Wright EST Group's Double Block & Bleed Isolation Plug helped a Spanish refiner safely streamline their hydrotesting process for minimal downtime and operational risk.

Curtiss-Wright EST Group's Double Block & Bleed Isolation Plug answers an industry need for more efficient and reliable isolation options for hydrotesting operations. The plug affords safe isolation of piping during pipeline repairs and can be quickly repositioned across new welds for hydrotesting—saving time and costs in the process.

The plug's dual port design creates a positive pressure barrier between the seals, safely isolating hot work from residual upstream gases or fluids, and allows water or other test media to circulate between the seals, providing improved cooling during pre- or post-weld procedures.



Double Block & Bleed Isolation Plug

The plug helped an ILBOC refinery in Spain conduct pressure tests within a tight maintenance schedule. The refinery's maintenance crew consulted with EST Group application specialists to select the proper plug size and seal material for their hydrotesting operations. Based on the refinery's specs, EST Group manufactured and delivered the plug quickly, allowing, ILBOC to conduct laboratory-simulated hydrotests to gain familiarity with the plug's operation and installation procedure prior to live testing.

"With the proper training from these lab simulations, we had assurance that we could safely install the plugs and carry out each hydrotest to the required pressure," explains Francisco Caparrós Quiles, Reliability Engineer at ILBOC. "It gave us the desired confidence to move the plug to the plant."

The plug's lightweight aluminum and steel body allowed ILBOC's maintenance crew to quickly position and move the plug from spool to spool, without the use of cranes or other heavy lifting devices. Since the plug could be deployed across a small section of pipe, the refiner was able to perform pressure tests with less than a gallon (3.8 L) of test media—significantly cutting down fill times and reducing waste/treatment expenses.

The isolation plug performance exceeded expectations in each line tested. The plug's seals reliably held pressure during each test, with some lines tested up to 325 BarG (4,714 PsiG). Pressure tests were successfully completed allowing the refiner to bring the lines back into service quickly while minimizing downtime and maintenance costs. Satisfied with the safety, reliability and overall performance of the isolation plugs, ILBOC plans to order additional plugs in other sizes.

Curtiss-Wright EST Group offers a full line of Test & Isolation plugs, and maintains a large inventory ready to ship globally. Additionally, 24/7 emergency design and manufacturing services are available to custom-build plugs to customers' specific application needs, including construction composition, pressure ratings, size ranges and seal materials.

www.cw-estgroup.com

Flowrox Now Offering Filter Parts and Services

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Flowrox is proud to launch two new filter products. The Flowrox Filter Press™ and Ceramic Disc Filter™ now complement the Flowrox Smart Filtration Digital Service. Together, all three of these filter products can be used to maximize performance and reduce total cost of ownership.

The Flowrox Filter Press is a fully automatic pressure filter and offers a long-term solution to maximize production, improve availability, and reduce OPEX. Flowrox's filtration experts have over 40 years of valuable filtration experience. Dedicated team will help choose the right filter and auxiliary equipment for each specific project.

The Flowrox Ceramic Disc (CD) Filter is highly efficient and has low energy consumption. Compared to conventional vacuum filters, it consumes approximately 90 % less energy. The Flowrox CD Filter is a low-cost filtration option that delivers excellent filtrate clarity along with dry cake. Like the Flowrox Filter Press, the CD Filter comes with the support of the Flowrox filtration experts.

Common applications for the Flowrox filters include iron, copper, zinc, gold, phosphates, molybdenum, phosphorus, mineral based chemical filtration, flue-gas desulfurization and quartz sand.

Adding the Smart Filtration Digital Service to any Flowrox filter product can significantly improve the production process. It enables remote, real-time insight into the filtration process and helps operators to troubleshoot and significantly optimize production. The entire process is digitized with the Flowrox Malibu™ platform, allowing the entire digital process to be available 24/7 from any computer, smart phone or any other handheld device with internet connection.

There's no need to be in the physical location. Smart Filtration Digital Service constantly analyzes and evaluates filtration process. If the system detects any abnormalities, it automatically sends alerts and notifications to user's email. Catching maintenance problems in advance will save on OPEX costs by allowing the user to fix the issue before it becomes a bigger, more expensive problem. With continuous data tracking and analyzation, the Smart Filtration Digital Service helps production running smoothly.

www.flowrox.com

Magnetrol® offers Pulsar® Model R86 for the oil and gas industry

The PULSAR Model R86 Non-Contact Radar transmitter from **Magnetrol®** provides improved level measurement performance in a wide range of petrochemical and petroleum refining applications, including storage tanks, mixing and blending operations, and drilling fluid tanks. The latest in MAGNETROL's full portfolio of level instrumentation, the Model R86 provides outstanding accuracy, reliability and safety.

Latest-generation features include:

Improved Performance

The 26GHz radar signal has a smaller wavelength, resulting in smaller antennas and improved resolution. This is an important distinction for some process vessels because the smaller beam angle allows for installation into process connections as small as 1 in. (33mm). As a result, the PULSAR Model R86 assures precise, dependable level measurement and control no matter the size or shape of the vessel or process connection.

Advanced Diagnostics

The user interface experience of the PULSAR Model R86 is driven by advanced diagnostics that transforms the way that radar level measurement is used. Automated echo capture conveys real-time waveform and trend data so users can assess the situation at a glance. In addition, the event history shows up to 20 events including diagnostic and configuration data to pinpoint any issues. Troubleshooting tips provide practical solutions that can help reduce downtime and lower maintenance costs.

True Versatility

The PULSAR Model R86 uses circular polarization, which eliminates the need to rotate the antenna orientation during commissioning. This simplifies installation and delivers proper alignment in virtually every application. High Temperature antennas are designed for use in operating conditions up to 750 oF (400 oC). Nozzle extensions ranging from 12 in. to 72 in. (0.3m to1.8 m) accommodate nonstandard nozzle lengths and buried vessel standpipes.

The PULSAR R86 introduction represents the latest radar innovation from MAGNETROL, which introduced the very first 2-wire, loop-powered guided wave radar transmitter for industrial liquid level applications. It's a highly effective solution for petrochemical and petroleum refining operations, as well as many other applications throughout the oil and gas and chemical industries.

For more information on the PULSAR R86 and other MAGNETROL products for petrochemical or petroleum refining applications, visit

www.magnetrol.com

The single source for emissions control

John Zink Hamworthy Combustion has been leading the industry for decades with continuous innovation and proven performance

John Zink Hamworthy Combustion (JZHC) invests heavily in facilities and experts. Their research and development center makes up the largest, most advanced testing facility of its kind, allowing engineers to push innovation, gain expertise and measure performance under real-world conditions. Experts use advanced computational fluid dynamics to solve turbulent fluid flow problems involving multiple-step chemical reactions and non-linear heat transfer. Researchers continually improve product performance and develop patented technologies that drive future solutions. JZHC offers:

Burners: A broad range of solutions through some of the industry's most trusted brands: Coen, Todd, John Zink, Hamworthy-Combustion, Peabody Engineering.

Flare systems: Advanced design and technologies set the standard for upstream, downstream and biogas flare industries.

Landfill and biogas: 700+ biogas flare systems in operation, including enclosed and elevated landfill systems, blower skids and the Ultra Low Emissions (ZULE) flare system, which delivers the highest destruction efficiency available with the lowest emissions.

Zolo laser combustion monitoring: Unique laser-based combustion monitoring and diagnostic capabilities for ultra-harsh environments to optimize the yield, efficiency, and safety of combustion applications.

Flare and vent gas recovery: Systems provide near-zero flaring, decreasing emissions and recovering flare gas to be re-used as fuel or feedstock for environmental control with an immediate return on investment.

Thermal oxidation: 2,500+ installed systems protect the environment by destroying up to 99.9999% of many hazardous wastes.

Air heaters and recuperators: KEU-brand solutions provide proven performance in extreme environments and tough applications.

Vapor control: 2,000+ vapor combustion and vapor recovery installations, utilizing technologies recognized as "Best Demonstrated Technology" and "Maximum Achievable Control Technology" by the U.S. Environmental Protection Agency.

Flue gas treatment: Selective Catalytic Reduction (SCR) and Selective Non-Catalytic Reduction (SNCR) solutions are designed to deliver up to 99% post-combustion NOx reduction.

ETI oil and gas processing: A broad range of solutions including glycol dehydrators, amine gas sweetening units, mechanical refrigeration units, fuel gas conditioning units, solid desiccant unit/mole sieve, filter separators and coalescers, carbon bed filters, liquids separation and dehydration solutions, and a variety of heat transfer products.

www.johnzinkhamworthy.com

Multiple Temperature Points – One Sensor

In any manufacturing operation, there are a variety of process variables that are monitored, measured and/or controlled. One of the most widely measured variables is temperature. The temperature of a material (be it gas, liquid or a solid) is seldom constant throughout the process. In some applications, small variations of a material temperature within the process may not be an issue, but in others, it is critical to monitor and/or control at a number of points. Measuring temperature of a process at multiple points can be accomplished by mounting an individual sensor at each location or by installing a single multi-point temperature sensor assembly. Both will provide the necessary information, however the multi-point sensor only requires one installation at one location with one control connection while measuring the material at numerous points along the process. Multi-point temperature sensors provide an economical and efficient way to handle several points of measure in a process.

In its simplest form a multi-point temperature sensor consists of a number of RTDs (Pt100s) or thermocouples encased at various points inside a sleeve, sheath, jacket or tube with a single access point at a junction enclosure. Multi-point sensors can be various lengths, sizes in diameter, made of a variety of materials, incorporate temperature transmitters, and constructed to measure a wide range of temperatures.

Multi-point temperature sensors are utilized in many industries, including but not limited to:

- chemical
- oil and gas
- petrochemical
- food and beverage
- dairy
- pharmaceutical
- power generation
- HVAC
- heat treating
- water and wastewater

These sensors are often used to measure multiple temperature points in storage tanks, piping systems, ovens/kilns/furnaces, air flow ducts, grain bins, heat exchangers, rail car and truck tanks, distillation columns, chemical vessels and others.

Depending on the application, multi-point temperature sensors provide detailed temperature profiles for optimized process control. They are often used to map temperatures over a large area, identify temperature gradients, or to detect hot spots within the process.

Pyromation manufactures a variety of standard and custom-designed multi-point temperature sensor assemblies that are used in applications in many industries around the world.

www.pyromation.com

BRB Control Room Suitability in the Chemical Industry

In March, two separate explosions and fires in the Houston area reminded those of us who work in, or close to the chemical industry of the risks and dangers present in chemical facilities. Chemical plants in Crosby and Deer Park, Texas both witnessed explosions and fires that resulted in injuries, damage, environmental impact, and negative public blowback. In both cases, it took several hours or more for crews to regain control over the incidents. In the meantime, nearby residents, schools, and businesses hunkered down under shelter-in-place orders. Both facilities are reportedly named in lawsuits.

During events like this, a facility's control over the situation can help save lives, minimize damage, and enable first responders to quickly and safely bring control to the situation. Quickly bringing control back to a hazardous event provides confidence and relief to authorities and those outside the facility witnessing the event.

Having a well-designed, properly sited control building is a critical piece of maintaining or regaining control during an event. A robust, engineered blast-resistant building (BRB) is an ideal upgrade to an aging stick-built or masonry control building that may not withstand an explosion, fire, or toxic release.

Blast-Resistance

Properly engineered BRBs are widely accepted as the quickest and most cost-efficient way to create a control room space that will withstand an explosion. Blast tests, recent history, and the continuous improvement of materials, production, and features gives chemical facilities a quality option for control rooms that allow operators to detect releases, sound alarms, shut down systems at risk, order evacuations, communicate with authorities, and most importantly, remain at stations through an explosive event to communicate and work with authorities.

Toxic Hazards

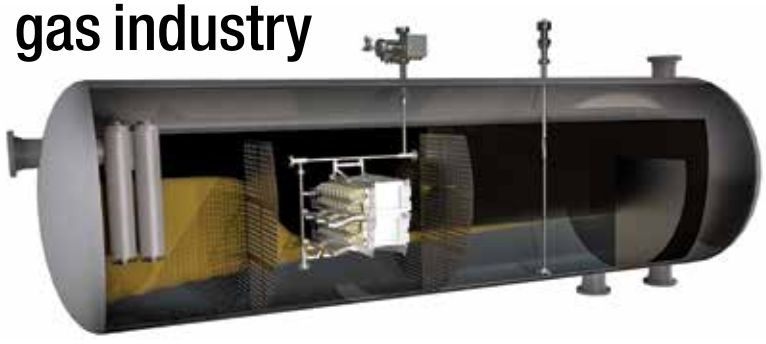
The industry's understanding of chemicals and each of their hazardous characteristics is exceptional. The design around a chemical facility BRB control room can sensibly address all of the possible hazardous scenarios so that evacuation of a control room during an event is not necessary. Various detection systems, fresh air intake, recirculation modes, and airtight building envelopes are simple features that keep operators managing an event – not evacuating.

Fire

A BRB is uniquely fire resistant – it's built with steel – and is recognized as a non-combustible building material by IBC. Fire suppression systems can be installed on the interior and exterior of a BRB to increase fire-resistance. The improvement and widespread availability of intumescent coatings (spray-applied fire resistive coatings) are very compatible with steel buildings. BRBs can be designed to specific duration specs to ensure safe occupation during a fire if an evacuation is not necessary.

Feel free to explore **RedGuard**'s family of protective buildings at **www.redguard.com**

Solutions for the oil and gas industry



With rising global demand, volatile prices and increasingly stringent environmental regulations, oil and gas companies are challenged to reduce their costs while improving their process performance. For over 50 years **Sulzer Chemtech** has been offering proven, cutting-edge mass transfer components to solve the challenges within the upstream, midstream and downstream sectors of the oil and gas industry and help businesses to boost their performance.

Sulzer Chemtech, a leader in separation and mixing technology, helps the oil and gas industry address these issues by delivering innovative yet reliable solutions and providing a global service and manufacturing network, supported by world-class experts.

The company offers reliable and high-performance solutions for upstream operations, including gas-liquid vessel internals, inline gas-liquid separators, vessel internal electrostatic coalescers (VIEC™) for liquid-liquid separation as well as sand separation systems.

VIEC™ uses alternating high-voltage electrical fields to separate oil and water. The system tolerates up to 100% water or 100% gas in a robust and stable process. The solution is well-suited to solve emulsion-related issues. In addition, the compact design offers an energy efficient and flexible technology that is also suitable for vessel revamps.

In the downstream sector, Sulzer Chemtech designs, manufactures and provides state-of-the-art separation systems that maximize crude oil processing capacity in crude and vacuum distillation units. Refineries can benefit from Sulzer's in-depth knowledge and expertise in the challenges affecting the processing operations and undermining plant productivity, such as foam formation, fouling by coke and salt deposition or erosion by sand/catalyst particles.

Refineries can also benefit from Sulzer's specialized fractionation tray portfolio designed to minimize fouling and corrosion. The VG AF™ (V-Grid Anti Fouling) trays, equipped with the high lift raised orifice valves XVG™ (Extra Large V-Grid) or SVG™, have excellent fouling resistance, increasing the system reliability, without impacting the column performance.

With Sulzer's solutions for upstream, midstream and downstream processes, businesses can improve the efficiency and productivity of their processing operations, produce higher quality products and optimize the service life of their equipment.

Choosing Sulzer and its separation technologies not only means having access to high-quality, reliable and innovative products, but also to a wide range of dedicated engineering services.

www.sulzer.com

Water Filter Applications for the Petrochemical Industry

There are many areas within petrochemical processing which use water that requires filtering.

By using a **Tekleen** self-cleaning automatic filter, this water can be cleaned of debris and solids, provide cooling, pre-filter water for further cleaning, and maintain the operational reliability of piping, spray heads and any devices that water flows through.

It can be used as a pre-filter down to 2 microns, protecting R/O and microfiltration systems used for potable water quality production. The filtered water can then be re-used and the debris properly disposed of. The filters operate on line pressure alone.

Types of Water Filter Applications for the Petrochemical Industry

1. Reverse Osmosis

This process uses reverse osmosis semi-permeable membranes to flush out impurities.

High pressure water is passed through the membrane, leaving behind contaminants and particles.

2. Cooling Water Tower

The water is cooled throughout the cycle by evaporation, which results in debris accumulation. With a Tekleen automatic filter, the debris is filtered out and contained for disposal, the filter cleans itself, and the cooling water continues to flow.

One such installation for providing cooling tower water uses a Tekleen 6" filter, with a flow rate of 600 GPM, at 50 PSI. The filter used is an ABW6-LP with a 100 micron high performance screen.

3. Underwater Pelletizing

Underwater pelletizing is a method of cutting extruded plastic into beads. This water can be recycled.

4. Potable Water

Petrochemical companies often provide potable water in housing and break room for employees. Tekleen filters can purify this water down to 2 microns to prefilter water going through an R/O or microfiltration process for safe drinking.

5.Polymer Filtration - used to settle mud

With the mud adequately settled and turbidity minimized, the Tekleen unit can filter the re-usable water, which can be sent to storage. The polymer beads are left behind to continue the settling process.

6.Well Water Seal Protection

Seals can be protected from excessive wear by using water to cool down the seal and the shaft, to lubricate the seal, and to flush away solids. One Tekleen installation uses a 2" filter, setup to provide 100 GPM. It uses a MTF2-XL 25 micron screen.

Several of the largest U.S. petrochemical plants use Tekleen filters for their various water requirements.

With proper filtration, source water for processing can successfully be derived from wells, ponds, rivers, rainwater, seawater and re-used water.

Tekleen self-cleaning water filters provide the ultimate solution where dirty water is a problem.

www.tekleen.com

ON COURSE IN DEEP COLD: 80-GHz radar level measurement makes cryogenic applications secure on the high seas

The liquid gas market is booming. LNG and LPG, liquefied natural gas and liquefied petroleum gas, are among the most promising sources of low-emission mobility in the future. When the first LNG-powered container and cruise ships are launched in the next few weeks, extraordinarily cold-tolerant level sensors will also be on board.

80 GHz radar level sensor VEGAPULS 64 is ideal for cryogenic applications on the high seas, withstanding temperatures as low as -196° C.

It is not only the extreme temperatures that make life difficult for measuring instruments when they are being used at sea or measuring liquefied gases. Petrochemical products are characterized by their low dielectric constants and are generally difficult to measure. Because they are temperature decoupled from the process, the 80-GHz radar sensors from VEGA are optimized for the extreme process temperatures that prevail in LNG applications: they easily withstand temperatures as low as -196° C. Ice does not form on the housing, nor is there any condensation on the antenna system. In addition to cryogenic applications, the specially protected housing and front-flush antenna cover of PTFE are also suitable for reliable measurement of aggressive media, whether acids, alkalis or abrasive substances.

From the top of the housing to the business end of the measuring cell, the sensor is extremely robust and equipped with high-quality components. The key element is its highly resistant stainless steel housing, which thermally decouples the sensitive electronics inside.

But it's also their high dynamic range that makes the 80-GHz radar sensors VEGAPULS 64 so unique they can detect even the tiniest of signals. This is especially important when measuring hydrocarbons. The sensors can detect virtually all media in the petrochemical industry, from crude oil to cryogenic liquefied gases, with high reliability despite their poor reflective properties.

VEGA's level and pressure measurement technology is based on many years of experience in developing custom-made products for industrial, storage and cargo tanks. Today, VEGA is able to keep up with the demands of the booming, worldwide LNG market by providing sophisticated measurement technology for cryogenic applications in land and sea transport.

www.vega.com

Do you know when to calibrate?

Failure to calibrate flowmeters can negatively impact performance, while calibrating too frequently can result in excessive costs without providing any benefits. So, the question is, how do you determine if calibration is needed and what the frequency should be?

In many process plants, flowmeters are calibrated annually or more frequently simply because that's the way it was done in the past. New instruments and technologies, combined with careful planning and study, can allow plants to calibrate flowmeters at an optimum frequency, resulting in improved operations and cost savings.

In many instances, yearly calibrations are not necessary, as some flowmeters require calibration only once every three or four years depending on the process fluid, operation, and criticality. In other cases, a flowmeter may require calibration much more frequently, possibly on a monthly basis, to maintain a safe, efficient, or regulatory compliant operation. It's also important to realize that calibration intervals are not always fixed, meaning that they might fluctuate based on usage or historical performance.

How do you determine when to calibrate a flowmeter? By setting up a calibration plan that follows best practices for flow calibration.

The first step in a calibration plan is to perform a plant-wide assessment (Installed Base Analysis) of all your instrumentation, including flowmeters. To do this, you must first identify and make a list of all the equipment parts and all instrument-related systems. This list should also include details such as description, location information, operating conditions, working range and history, and any other points that provide a better understanding of the instrument and system function.

After an installed base analysis has been performed, it is important to categorize all flowmeters by critical importance. Flowmeters fall into one of four categories, ranging from critical to noncritical importance. After all flowmeters have been identified and classified into these four categories, a Maximum Permissible Error (MPE) is assigned to each device. MPEs define the tolerance for each function being measured. A critical flowmeter will usually have a more stringent MPE than a non-critical flowmeter. Flowmeter data from the analysis should be stored in an asset management, maintenance management, or instrumentation management program.

Setting up a flow calibration plan for individual instruments often requires assistance from the flowmeter manufacturer and a qualified calibration company with industry experience, as they are best qualified to advise on how often a flowmeter should be calibrated in a typical installation. The end-user must then use this advice and apply it based on particular service conditions, functions of the meter and their experience.

For more details, visit **www.us.endress.com/flow-calibration**

Delivering proven technology and solutions for heat exchanger performance

HTRI provides value to customers through innovative products and comprehensive services.

The High Temperature Fouling Unit provides thermal fouling and pressure drop data for hydrocarbon fluids.

HTRI is a leading source of process heat transfer technology. For more than half a century, HTRI has conducted applied research in heat transfer and fluid flow technology for the design and simulation of process heat transfer equipment. From the collected data, HTRI has developed reliable heat transfer and pressure drop methods, providing this expertise to customers through a variety of products and services, including software solutions.

Throughout the world, HTRI's acclaimed Xchanger Suite is considered to be the most advanced thermal process design and simulation software. Each of Xchanger Suite's nine modules are highly flexible, allowing rigorous specification of exchanger geometry and resulting in the most accurate performance predictions possible for various exchanger types.

Exchanger Optimizer, an innovative economic evaluation tool, is now integrated with Xchanger Suite 8. By downloading Xchanger Suite 8, licensed users of Exchanger Optimizer can access the embedded costing feature, which provides fabrication, installation, and operational estimates in Xist and Xace design cases. Exchanger Optimizer can be launched from within Xchanger Suite to generate comprehensive cost assessments and validate designs based on ASME code calculations.

Refining companies have increasingly adopted SmartPM, the performance monitoring and predictive maintenance software for improving operations of shell-and-tube heat exchanger networks. SmartPM uses plant data and HTRI's detailed proprietary heat exchanger calculation methods to evaluate past performance and predict future refinery throughput, energy consumption, emissions, and optimum heat exchanger cleaning schedules. With SmartPM, refineries are able to better understand the operation of their networks and achieve significant savings.

Contract services are available to both members and non-members. HTRI's technical services group can help companies address diverse heat exchanger issues to improve exchanger performance or throughput, reduce fouling, or troubleshoot equipment. Testing is performed at the Research & Technology Center (RTC), located in Navasota, Texas, USA. With eleven operating research units, the RTC provides a controlled environment to evaluate the performance of heat exchangers and enhanced heat transfer surfaces, measure the fouling potential of crude oil and petroleum products, study process phenomena, and more.

HTRI also provides the most comprehensive training program for heat exchanger technology and its application in industry. Each year, HTRI trains end users around the world through online or face-to-face interactions. Live and recorded webinars are also available on the HTRI website and are free of charge to HTRI members.

www.htri.net

Milton Roy Critical Chemical Dosing Pumps and Mixing Systems

Built on a strong reputation of reliability, **Milton Roy** combines vast industry experience, a proven track record, and a culture of continuous technological improvement to deliver the most comprehensive portfolio of metering pumps, mixers and control systems for chemical metering applications used in upstream applications and industrial water and wastewater treatment.

Milton Roy's PRIMEROYAL® Series metering pumps are the industry's most powerful metering pumps, capable of delivering 20,000 psig to overcome the extreme pressures associated with ultra-deep offshore applications. The API 675 compliant PRIMEROYAL pump is designed for consistent and accurate delivery of flow assurance chemicals to enhance offshore product recovery, eliminate corrosion, and prevent hydrates or wax deposit formations. The PRIMEROYAL range provides accurate dosing of a broad spectrum of fluids at flow rates that can reach maximum 13,068 gph (49,470 l/h) in the triplex configuration. With its modular design, multiple liquid ends, and wide range of options, PRIMEROYAL pumps can be configured precisely for many dosing applications.

The workhorse of the Milton Roy portfolio is the mROY® metering pump. This pump has been upgraded and offers enhanced safety, improved hydraulic efficiency, easier startup and maintenance, and the same accuracy and reliable performance for which Milton Roy is known. Produced in a variety of models and frame sizes that provide capacities from 0.20 gallons per hour up to 87 gallons per hour in a simplex configuration, the mROY metering pump boasts a hydraulically balanced diaphragm with 96,000-hour design life and a three-year warranty.

Milton Roy's PROTEUS® is the most intelligent chemical metering pump for the water and wastewater, chemical, power generation, oil and gas, agricultural, pulp and paper, and textile industries. PROTEUS is built on a universal

technology platform with the ability to adapt as technology evolves. It features a mechanically actuated diaphragm driven by advanced variable speed technology for accurate and reliable performance. PROTEUS is available in manual or enhanced models with flow rates 0.006 to 18 gallons per hour (0.023 to 68 liters per hour to provide complete process control.

In addition to metering pumps, Milton Roy offers a range of mixers and agitators used for water treatment processes and flocculation and coagulation applications. Milton Roy provides side entry mixers used by crude oil storage operators to blend crude of different gravities together until it can be sent to refineries. This efficient blending keeps basic sediment and water (BS&W) from settling at the tank bottom, which protects storage tanks, and maximizes storage space for operators.

www.miltonroy.com

The Gulf Coast Depends on Zeeco

Whether you face a full-scale emergency or a simple maintenance need, renting the right combustion equipment can be frustrating. **Zeeco** maintains a full fleet of easily installed rental equipment staged for rapid deployment. Zeeco rental equipment includes flare systems, flare monitoring and control systems, incinerators / thermal oxidizers, and vapor combustors.

Our aftermarket parts and service team delivers the same attention to detail, engineered expertise, and on time, on spec performance – whether you have Zeeco equipment or not.

Rental flare systems are used in multiple ways: safe disposal of pipeline contents when sections need repair or inspection, evacuation of large tanks for maintenance or analysis, or interim use when the primary flare must be shut down. Customers rent Zeeco's temporary flare systems for open and enclosed trailer mounted applications, or in ready-to-assemble pieces delivered to the jobsite. Zeeco open flaring rental systems range from small skid or trailer mounted flares up to 60'-tall to elevated systems more than 300-foot-tall.

Deploying the FlareGuardian™ real-time flare monitoring and control system and/or the Contour™ system for optimized steam / air control can help customers ensure proper flare operation and compliance with the Refinery Sector Rule (RSR) regulations. FlareGuardian is an innovative and revolutionary instrument for direct flare monitoring, utilizing patented Video Imaging Spectro-Radiometry (VISR) technology. It provides flare system users and operators with accurate, reliable, real-time reporting to determine important performance metrics, simplify compliance, and optimize flare performance. By directly monitoring flare performance, including Combustion Efficiency (CE) and smoke index, flares can be operated at the incipient smoke point day and night. FlareGuardian eliminates the costs of separate instrumentation and maintenance for continuous gas composition analysis, flow monitoring (flare gas, steam, and air), pilot monitoring, and visible emissions monitoring.

Zeeco maintains a rental fleet of trailer-mounted vapor combustors that can dispose of streams ranging from very small vents to 30,000 cfm contaminated air streams. These enclosed systems perform like thermal oxidizers with destruction efficiencies that meet or exceed the most stringent clean-air standards. Designed to use both combustion and quench air, Zeeco's vapor combustors maintain precise chamber temperatures to ensure maximum destruction and removal efficiencies.

Rental incinerators are often used to destroy wastes generated by gas treating plants (tail or acid gases), glycol dehydration units, and specialty process plants, as well as wellhead and pipeline testing activities.

For more information, contact sales@zeeco.com or call 918 258 8551.

www.zeeco.com

Confident that you still rely on the very best solution for production of your chemicals?

In the chemicals industry, there is no room for compromises. Not just in terms of safety and product purity, but also when it comes to non-stop performance. And as technologies and global supply chains become more complex, **ANDRITZ** has proven that it can provide "next practice" solutions for its demanding customers to keep them at the forefront of their industries.

SEPARATION CHALLENGE? – CONSIDER IT SOLVED!

In terms of product purity, plant safety, and reliability, chemical manufacturers are among the most demanding customers. And market conditions are changing fast. Whatever the separation challenge might be, ANDRITZ is considered by industry leaders to be the in-depth engineering expert, with a wide range of technologies and the most comprehensive service offering to cover customers' entire plant life cycle.

SPECIFIC PROCESS REQUIREMENTS? – CONSIDER THEM UNDERSTOOD!

Selecting the best possible technology must be based on strict process requirements and the characteristics of the chemicals used in the processes. With 150 years of process expertise in the field, ANDRITZ can provide assistance and guidance in selecting the right solution uncompromisingly from a broad technology portfolio ranging from vacuum and pressurized drum filters, filter and belt presses, decanter centrifuges, filtering centrifuges (pusher, peeler), and separators, to drying/cooling systems and much more. For a tailored approach, ANDRITZ further refines and tests solutions on-site or in one of its own state-of-the-art test centers. The proven results are high-purity end products manufactured with the right technologies to ensure efficient, sustainable, safe, and reliable operations for decades.

SUPERIOR SERVICE AND AUTOMATION? – ASK YOUR SEPARATION SPECIALIST!

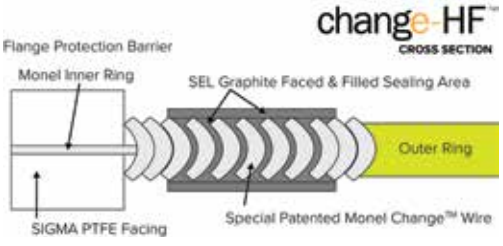
Thanks to the global network of 550 service specialists for solid/liquid separation equipment and systems as well as service centers all around the world, ANDRITZ is on hand to ensure its customers' investments always deliver the maximum value. In addition to readily available OEM parts, process optimizations, testing capabilities, and much more, ANDRITZ also offers a wide range of automation tools. When it comes to automation and process control, the Metris addIQ control systems combine all of ANDRITZ's extensive operation, troubleshooting, and start-up experience in one tailored automation solution. With the broad portfolio of scalable automation solutions, applicable over a wide range of tasks including predictive maintenance, process monitoring, troubleshooting, and long-term trending, ANDRITZ has already achieved "Chemicals 4.0" today, reducing risks, increasing availability, and thus improving its clients' ecological footprint as well as sustaining their long-term business success.

www.andritz.com/separation

Gasket Technology 100 Years In The Making

Flexitallic invented the spiral wound gasket over 106 years ago; the Change gasket is their next generation of sealing technology.

The Change gasket has become the most significant development in the gasket and sealing industry in the past five years with more than 100,000 gaskets sold around the world into sectors such as Steel, Power, Chemical, Refining, and Pulp & Paper. Developed by Flexitallic in direct response to customers' long-term heat exchanger sealing problems, the Change gasket is a highly-resilient metal-wound gasket, designed to deliver the most dynamic static sealing technology ever. Manufactured using proprietary equipment, the Change gasket has a proven track-record showing it outperforms conventional gasket technology in challenging environments, especially in applications with mechanical and thermal cycling conditions. It has also achieved independent industry accreditation from TA Luft for its ability to deliver the tightness of a Kammprofile with the recovery of a spiral wound gasket. This is achieved through the application of a unique metal spiral profile, which is more advanced than those found in standard gaskets. This profile, combined with a laser welding process, facilitates the construction of a robust and dynamic seal. The unique wire profile stores more elastic energy to create better dynamic performance and superior load retention in cyclic applications. This leads to excellent recovery (tested with 34% recovery @ 18K PSI [124 MPa], 30% compression). With these dynamic characteristics, there is no need for spring washers or re-torquing. This allows the gasket to cycle over & over, and maintain sealability. Furthermore, from the Change gasket design, a new corrosion-resistant family of Change gaskets was born; Change-HF (HF Alky applications), Change-SF for (Sulfuric Acid applications) and the Change-CR (other corrosive applications). The Change-HF is constructed like a standard Change gasket, but includes an inner ring barrier (monel, faced with Sigma PTFE) that protects the flange from acid corrosion and also fills any existing corrosion damage. The sealing portion consists of a special patented Monel



Change wire with graphite facing and filler. This Change gasket technology combined with the Sigma flange protection barrier allows the Change-HF to far outperform other similar gaskets on the market. The Change gasket has had much success including being selected as the replacement gasket for a major national refiner; switching all of their HF-Alky gaskets to the Change-HF. The Change gasket along with the Corrosion Protection product line offers the newest and best-in-class innovations solving their customers' sealing challenges now and well into the future. For more information on the Change gasket, visit

www.Flexitallic.com/change

Your First and Only Call for Refractory


KORUNDAL XD

There are many different vessels in a refinery that require refractory linings and each one can use several different kinds of refractory inside. The process of identifying and obtaining refractory can be complicated, especially when multiple sources are used. **HarbisonWalker International** (HWI) aims to resolve this complication by not only offering every product needed in a refinery, but by also identifying which products and how much are needed. They can provide products for fluid catalytic cracking units (FCCU), sulfur recovery units (SRU), and fired heaters and reformers. Technical support is available to identify the brands required for a given unit and even offer some advice for improvements. Bills of material and refractory drawings can be made for anything from a simple duct to the most complex brick linings.

For the FCCU, HWI can offer excellent products that are made to endure the challenging environment inside. For reactor and regenerator walls, GREENLITE®-45-L has been used for many years with great success. This product's success is largely due to the superior strength-to-density ratio created from the use of Greenlite® Aggregate, a proprietary synthetic lightweight aggregate with great strength. There is even a version available that can be pumped or shotcreted into place. For more abrasive areas of the FCCU like the riser and transfer lines, the medium-weight products HPV® 110 and LO-ABRADE® HPI have an excellent abrasion resistance as low as 12cc loss maximum (tested with ASTM C704), but still provide good heat insulation. For areas with the worst abrasion problems, GREENKLEEN® 60 (for casting) and EXCELERATE ABR (for ramming) are perfect with abrasion loss as low as 5cc loss max.

In SRU thermal reactors only the highest quality refractory brick can be used for the hot face layer of the refractory lining. Brick in this area need to have the best creep resistance to hold up to the extremely high temperatures for many years. This is why KORUNDAL XD® has been the go-to refractory brick for SRU thermal reactors for decades that few competitors can match. Behind the hot face layer will be a layer of GREENTHERM™ insulating firebrick or KAST-O-LITE® lightweight castable. Other areas downstream of the thermal reactor will require a variety of lightweight and dense monolithic refractory, all of which HWI can provide solutions for.

Fired heaters can range widely by design and function. No matter what the design or temperature, HWI can provide the refractory needed. With a range of insulating castables, all temperature ranges can be covered. HWI even manufactures its own ceramic fiber blanket which can be used as-is for blanket linings, or purchased and installed as a folded module for better insulation and durability in service. Creep resistant firebrick are also available for tunnel and division walls where deformation of refractory over time causes these walls to break down.

No matter who provided the refractory in the past, or if the last time it was repaired was in the '60s, HWI can provide the proper refractory product needed. Experts are available to help design the lining needed for any unit. We strive to be your first and only call for refractory products.

www.thinkhwi.com

Fluid Hacks: Tips to Optimize Your Thermal Fluid Operations

Charging a System:

Avoid filling systems from the top-down (ie from the expansion tank) as you will effectively trap air into the loop resulting in troublesome pressure fluctuations & pump cavitation. Removing air from the system is a painstaking process. Instead, fill the system from the lowest convenient point to push the air up and out of the system in its natural progression. Open all high point vents/valves and close as the fluid reaches each point.

Removing Water:

Avoid flashing moisture off into concentrated steam by controlling the temperature rise slowly to just above the boiling point of water (target around 230oF at standard atmospheric pressure). Open the warm-up or boil-out valve on the bypass leg to the expansion tank. This will allow hot fluid to flow directly into the tank and raise tank headspace temperature. As water boils, steam will escape through the vented expansion tank. Continue until no further visual evidence of steam and CLOSE THE WARM UP VALVE!

Prevent Rapid Degradation:

- Never operate above the maximum fluid operating temperature
- Maintain designed fluid flow rates through the heater
- Monitor differential pressure through the heater and low level switch in the expansion tank
- Never operate with the "warm-up" or "boil-out" valve open to allow for hot fluid flow directly into the expansion tank, unless you are actively removing water. Keep this valve CLOSED under normal operating conditions
- Install a low pressure inert gas blanket to displace air in the headspace of the expansion tank. Nitrogen is most common.
- Follow proper start-up and shut-down procedures

A collection of tips and practical guidelines from industry experts on thermal fluids and related operations...summarized advice intended to take the guesswork out of dealing with heat transfer fluids and to improve the overall user experience. For more detailed information on these Fluid Hacks and other heat transfer fluid related tips, visit

www.Paratherm.com/tipsheet

Economic Indicators

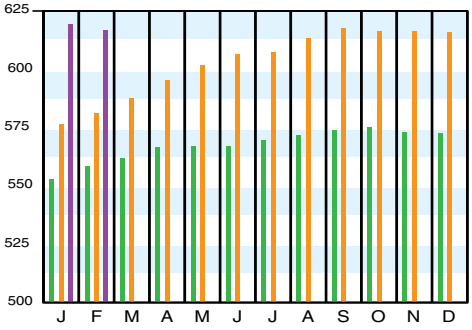
2017 2018 2019

Download the CEPCI two weeks sooner at www.chemengonline.com/pci

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	Feb. '19 Prelim.	Jan. '19 Final	Feb. '18 Final
CE Index	616.8	618.7	581.0
Equipment	754.3	756.9	703.3
Heat exchangers & tanks	674.0	676.5	616.2
Process machinery	728.0	732.2	700.3
Pipe, valves & fittings	971.7	978.9	903.6
Process instruments	418.9	416.0	416.9
Pumps & compressors	1063.8	1060.6	1009.6
Electrical equipment	554.4	554.7	532.0
Structural supports & misc.	838.0	841.1	755.5
Construction labor	333.4	333.9	330.3
Buildings	599.5	601.6	576.5
Engineering & supervision	316.0	316.9	310.7

Annual Index:
2011 = 585.7
2012 = 584.6
2013 = 567.3
2014 = 576.1
2015 = 556.8
2016 = 541.7
2017 = 567.5
2018 = 603.1

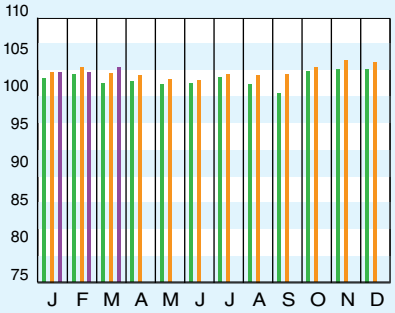


Starting in April 2007, several data series for labor and compressors were converted to accommodate series IDs discontinued by the U.S. Bureau of Labor Statistics (BLS). Starting in March 2018, the data series for chemical industry special machinery was replaced because the series was discontinued by BLS (see *Chem. Eng.*, April 2018, p. 76–77.)

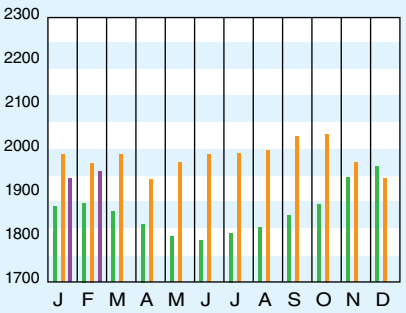
CURRENT BUSINESS INDICATORS

	LATEST	PREVIOUS	YEAR AGO
CPI output index (2012 = 100)	Mar. '19 = 103.4	Feb. '19 = 103.1	Mar. '18 = 102.6
CPI value of output, $ billions	Feb. '19 = 1,951.1	Jan. '19 = 1,937.7	Feb. '18 = 1,919.8
CPI operating rate, %	Mar. '19 = 77.5	Feb. '19 = 77.4	Mar. '18 = 77.4
Producer prices, industrial chemicals (1982 = 100)	Mar. '19 = 257.9	Feb. '19 = 255.1	Mar. '18 = 272.1
Industrial Production in Manufacturing (2012 =100)*	Mar. '19 = 105.5	Feb. '19 = 105.6	Mar. '18 = 104.5
Hourly earnings index, chemical & allied products (1992 = 100)	Mar. '19 = 183.6	Feb. '19 = 185.3	Mar. '18 = 190.0
Productivity index, chemicals & allied products (1992 = 100)	Mar. '19 = 95.1	Feb. '19 = 95.4	Mar. '18 = 98.4

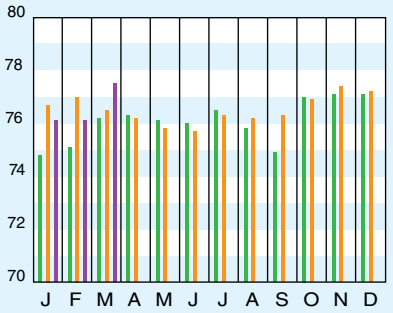
CPI OUTPUT INDEX (2000 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2000 to 2012
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The preliminary value for the *CE* Plant Cost Index (CEPCI; top; the most recent available) for February 2019 decreased from the previous month's value. In addition, the final value for the January 2019 CEPCI was downwardly revised by a modest amount compared to the preliminary value. All four major subindices of the CEPCI — Equipment, Engineering & Supervision, Buildings and Construction Labor — decreased in February. The overall CEPCI preliminary value for February 2019 stands at 6.2% higher than the corresponding value from February of a year ago. Meanwhile, the CBI numbers for March 2019 (middle) show the CPI Output Index and the CPI Operating Rate both edging upward.